



APPENDIX A

NIOSH METHODS

7400 PCM METHOD

7402 TEM METHOD

Various

MW: Various

CAS: Various

RTECS: Various

METHOD: 7400, Issue 2

EVALUATION: FULL

Issue 1: Rev. 3 on 15 May 1989

Issue 2: 15 August 1994

OSHA : 0.1 asbestos fiber (> 5 µm long)/cc;
1 f/cc/30 min excursion; carcinogen

MSHA: 2 asbestos fibers/cc

NIOSH: 0.1 f/cc (fibers > 5 µm long)/400 L; carcinogen

ACGIH: 0.2 crocidolite; 0.5 amosite; 2 chrysotile and other
asbestos, fibers/cc; carcinogen

PROPERTIES: solid, fibrous, crystalline, anisotropic

SYNONYMS [CAS #]: actinolite [77536-66-4] or ferroactinolite [15669-07-5]; amosite [12172-73-5]; anthophyllite [77536-67-5]; chrysotile [12001-29-5]; serpentine [18786-24-8]; crocidolite [12001-28-4]; tremolite [77536-68-6]; amphibole asbestos [1332-21-4]; refractory ceramic fibers [142844-00-6]; fibrous glass.

SAMPLING		MEASUREMENT	
SAMPLER:	FILTER (0.45- to 1.2-µm cellulose ester membrane, 25-mm; conductive cowl on cassette)	TECHNIQUE:	LIGHT MICROSCOPY, PHASE CONTRAST
FLOW RATE*:	0.5 to 16 L/min	ANALYTE:	fibers (manual count)
VOL-MIN*:	400 L @ 0.1 fiber/cc	SAMPLE PREPARATION:	acetone - collapse/triacetin - immersion
-MAX*:	(step 4, sampling) *Adjust to give 100 to 1300 fiber/mm ²	COUNTING RULES:	described in previous version of this method as "A" rules [1,3]
SHIPMENT:	routine (pack to reduce shock)	EQUIPMENT:	1. positive phase-contrast microscope 2. Walton-Beckett graticule (100-µm field of view) Type G-22 3. phase-shift test slide (HSE/NPL)
SAMPLE STABILITY:	stable	CALIBRATION:	HSE/NPL test slide
BLANKS:	2 to 10 field blanks per set	RANGE:	100 to 1300 fibers/mm ² filter area
ACCURACY		ESTIMATED LOD:	7 fibers/mm ² filter area
RANGE STUDIED:	80 to 100 fibers counted	PRECISION (\bar{S}_r):	0.10 to 0.12 [1]; see EVALUATION OF METHOD
BIAS:	See EVALUATION OF METHOD		
OVERALL PRECISION (\bar{S}_r):	0.115 to 0.13 [1]		
ACCURACY:	See EVALUATION OF METHOD		

APPLICABILITY: The quantitative working range is 0.04 to 0.5 fiber/cc for a 1000-L air sample. The LOD depends on sample volume and quantity of interfering dust, and is <0.01 fiber/cc for atmospheres free of interferences. The method gives an index of airborne fibers. It is primarily used for estimating asbestos concentrations, though PCM does not differentiate between asbestos and other fibers. Use this method in conjunction with electron microscopy (e.g., Method 7402) for assistance in identification of fibers. Fibers < ca. 0.25 µm diameter will not be detected by this method [4]. This method may be used for other materials such as fibrous glass by using alternate counting rules (see Appendix C).

INTERFERENCES: If the method is used to detect a specific type of fiber, any other airborne fiber may interfere since all particles meeting the counting criteria are counted. Chain-like particles may appear fibrous. High levels of non-fibrous dust particles may obscure fibers in the field of view and increase the detection limit.

OTHER METHODS: This revision replaces Method 7400, Revision #3 (date 5/15/89).

REAGENTS:

1. Acetone,* reagent grade.
2. Triacetin (glycerol triacetate), reagent grade.

* See SPECIAL PRECAUTIONS.

EQUIPMENT:

1. Sampler: field monitor, 25-mm, three-piece cassette with ca. 50-mm electrically conductive extension cowl and cellulose ester filter, 0.45- to 1.2- μ m pore size, and backup pad.

NOTE 1: Analyze representative filters for fiber background before use to check for clarity and background. Discard the filter lot if mean is ≥ 5 fibers per 100 graticule fields. These are defined as laboratory blanks. Manufacturer-provided quality assurance checks on filter blanks are normally adequate as long as field blanks are analyzed as described below.

NOTE 2: The electrically conductive extension cowl reduces electrostatic effects. Ground the cowl when possible during sampling.

NOTE 3: Use 0.8- μ m pore size filters for personal sampling. The 0.45- μ m filters are recommended for sampling when performing TEM analysis on the same samples. However, their higher pressure drop precludes their use with personal sampling pumps.

NOTE 4: Other cassettes have been proposed that exhibit improved uniformity of fiber deposit on the filter surface, e.g., bellmouthed sampler (Envirometrics, Charleston, SC). These may be used if shown to give measured concentrations equivalent to sampler indicated above for the application.

2. Personal sampling pump, battery or line-powered vacuum, of sufficient capacity to meet flow-rate requirements (see step 4 for flow rate), with flexible connecting tubing.
3. Wire, multi-stranded, 22-gauge; 1", hose clamp to attach wire to cassette.
4. Tape, shrink- or adhesive-.
5. Slides, glass, frosted-end, pre-cleaned, 25 x 75-mm.
6. Cover slips, 22- x 22-mm, No. 1-1/2, unless otherwise specified by microscope manufacturer.
7. Lacquer or nail polish.
8. Knife, #10 surgical steel, curved blade.
9. Tweezers.

EQUIPMENT:

10. Acetone flash vaporization system for clearing filters on glass slides (see ref. [5] for specifications or see manufacturer's instructions for equivalent devices).
11. Micropipets or syringes, 5- μ L and 100- to 500- μ L.
12. Microscope, positive phase (dark) contrast, with green or blue filter, adjustable field iris, 8 to 10X eyepiece, and 40 to 45X phase objective (total magnification ca. 400X); numerical aperture = 0.65 to 0.75.
13. Graticule, Walton-Beckett type with 100- μ m diameter circular field (area = 0.00785 mm²) at the specimen plane (Type G-22). Available from Optometrics USA, P.O. Box 699, Ayer, MA 01432 [phone (508)-772-1700], and McCrone Accessories and Components, 850 Pasquinelli Drive, Westmont, IL 60559 [phone (312) 887-7100].
NOTE: The graticule is custom-made for each microscope. (see APPENDIX A for the custom-ordering procedure).
14. HSE/NPL phase contrast test slide, Mark II. Available from Optometrics USA (address above).
15. Telescope, ocular phase-ring centering.
16. Stage micrometer (0.01-mm divisions).

SPECIAL PRECAUTIONS: Acetone is extremely flammable. Take precautions not to ignite it. Heating of acetone in volumes greater than 1 mL must be done in a ventilated laboratory fume hood using a flameless, spark-free heat source.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. To reduce contamination and to hold the cassette tightly together, seal the crease between the cassette base and the cowl with a shrink band or light colored adhesive tape. For personal sampling, fasten the (uncapped) open-face cassette to the worker's lapel. The open face should be oriented downward.
NOTE: The cowl should be electrically grounded during area sampling, especially under conditions of low relative humidity. Use a hose clamp to secure one end of the wire (Equipment, Item 3) to the monitor's cowl. Connect the other end to an earth ground (i.e., cold water pipe).
3. Submit at least two field blanks (or 10% of the total samples, whichever is greater) for each set of samples. Handle field blanks in a manner representative of actual handling of associated samples in the set. Open field blank cassettes at the same time as other cassettes just prior to sampling. Store top covers and cassettes in a clean area (e.g., a closed bag or box) with the top covers from the sampling cassettes during the sampling period.
4. Sample at 0.5 L/min or greater [6]. Adjust sampling flow rate, Q (L/min), and time, t (min), to produce a fiber density, E, of 100 to 1300 fibers/mm² ($3.85 \cdot 10^4$ to $5 \cdot 10^5$ fibers per 25-mm filter with effective collection area $A_c = 385$ mm²) for optimum accuracy. These variables are related to the action level (one-half the current standard), L (fibers/cc), of the fibrous aerosol being sampled by:

$$t = \frac{A_c \cdot E}{Q \cdot L \cdot 10^3}, \text{ min.}$$

NOTE 1: The purpose of adjusting sampling times is to obtain optimum fiber loading on the filter. The collection efficiency does not appear to be a function of flow rate in the range of 0.5 to 16 L/min for asbestos fibers [7]. Relatively large diameter fibers (>3 µm) may exhibit significant aspiration loss and inlet deposition. A sampling rate of 1 to 4 L/min for 8 h is appropriate in atmospheres containing ca. 0.1 fiber/cc in the absence of significant amounts of non-asbestos dust. Dusty atmospheres require smaller sample volumes (≤400 L) to obtain countable samples. In such cases take short, consecutive samples and average the results over the total collection time. For documenting episodic exposures, use high flow rates (7 to 16 L/min) over shorter sampling times. In relatively clean atmospheres, where targeted fiber concentrations are much less than 0.1 fiber/cc, use larger sample volumes (3000 to 10000 L) to achieve quantifiable loadings. Take care, however, not to overload the filter with background dust. If ≥ 50% of the filter surface is covered with particles, the filter may be too overloaded to count and will bias the measured fiber concentration.

NOTE 2: OSHA regulations specify a minimum sampling volume of 48 L for an excursion measurement, and a maximum sampling rate of 2.5 L/min [3].

5. At the end of sampling, replace top cover and end plugs.
6. Ship samples with conductive cowl attached in a rigid container with packing material to prevent jostling or damage.

NOTE: Do not use untreated polystyrene foam in shipping container because electrostatic forces may cause fiber loss from sample filter.

SAMPLE PREPARATION:

NOTE 1: The object is to produce samples with a smooth (non-grainy) background in a medium with refractive index ≤1.46. This method collapses the filter for easier focusing and produces permanent (1 - 10 years) mounts which are useful for quality control and interlaboratory comparison. The aluminum "hot block" or similar flash vaporization techniques may be used outside the laboratory [2]. Other mounting techniques meeting the above criteria may also be used (e.g., the laboratory fume hood procedure for generating acetone vapor as described in Method 7400 - revision of 5/15/85, or the non-permanent field mounting technique used in P&CAM 239 [3,7,8,9]). Unless the effective filtration area is known, determine the area and record the information referenced against the sample ID number [1,9,10,11].

NOTE 2: Excessive water in the acetone may slow the clearing of the filter, causing material to be washed off the surface of the filter. Also, filters that have been exposed to high humidities prior to clearing may have a grainy background.

7. Ensure that the glass slides and cover slips are free of dust and fibers.
8. Adjust the rheostat to heat the "hot block" to ca. 70 °C [2].
NOTE: If the "hot block" is not used in a fume hood, it must rest on a ceramic plate and be isolated from any surface susceptible to heat damage.
9. Mount a wedge cut from the sample filter on a clean glass slide.
 - a. Cut wedges of ca. 25% of the filter area with a curved-blade surgical steel knife using a rocking motion to prevent tearing. Place wedge, dust side up, on slide.
NOTE: Static electricity will usually keep the wedge on the slide.

- b. Insert slide with wedge into the receiving slot at base of "hot block". Immediately place tip of a micropipet containing ca. 250 μ L acetone (use the minimum volume needed to consistently clear the filter sections) into the inlet port of the PTFE cap on top of the "hot block" and inject the acetone into the vaporization chamber with a slow, steady pressure on the plunger button while holding pipet firmly in place. After waiting 3 to 5 sec for the filter to clear, remove pipet and slide from their ports.

CAUTION: Although the volume of acetone used is small, use safety precautions. Work in a well-ventilated area (e.g., laboratory fume hood). Take care not to ignite the acetone. Continuous use of this device in an unventilated space may produce explosive acetone vapor concentrations.

- c. Using the 5- μ L micropipet, immediately place 3.0 to 3.5 μ L triacetin on the wedge. Gently lower a clean cover slip onto the wedge at a slight angle to reduce bubble formation. Avoid excess pressure and movement of the cover glass.

NOTE: If too many bubbles form or the amount of triacetin is insufficient, the cover slip may become detached within a few hours. If excessive triacetin remains at the edge of the filter under the cover slip, fiber migration may occur.

- d. Mark the outline of the filter segment with a glass marking pen to aid in microscopic evaluation.
- e. Glue the edges of the cover slip to the slide using lacquer or nail polish [12]. Counting may proceed immediately after clearing and mounting are completed.

NOTE: If clearing is slow, warm the slide on a hotplate (surface temperature 50 °C) for up to 15 min to hasten clearing. Heat carefully to prevent gas bubble formation.

CALIBRATION AND QUALITY CONTROL:

10. Microscope adjustments. Follow the manufacturers instructions. At least once daily use the telescope ocular (or Bertrand lens, for some microscopes) supplied by the manufacturer to ensure that the phase rings (annular diaphragm and phase-shifting elements) are concentric. With each microscope, keep a logbook in which to record the dates of microscope cleanings and major servicing.
 - a. Each time a sample is examined, do the following:
 - (1) Adjust the light source for even illumination across the field of view at the condenser iris. Use Kohler illumination, if available. With some microscopes, the illumination may have to be set up with bright field optics rather than phase contract optics.
 - (2) Focus on the particulate material to be examined.
 - (3) Make sure that the field iris is in focus, centered on the sample, and open only enough to fully illuminate the field of view.
 - b. Check the phase-shift detection limit of the microscope periodically for each analyst/microscope combination:
 - (1) Center the HSE/NPL phase-contrast test slide under the phase objective.
 - (2) Bring the blocks of grooved lines into focus in the graticule area.

NOTE: The slide contains seven blocks of grooves (ca. 20 grooves per block) in descending order of visibility. For asbestos counting the microscope optics must completely resolve the grooved lines in block 3 although they may appear somewhat faint, and the grooved lines in blocks 6 and 7 must be invisible when centered in the graticule area. Blocks 4 and 5 must be at least partially visible but may vary slightly in visibility between microscopes. A microscope which fails to meet these requirements has resolution either too low or too high for fiber counting.
 - (3) If image quality deteriorates, clean the microscope optics. If the problem persists, consult the microscope manufacturer.
11. Document the laboratory's precision for each counter for replicate fiber counts.
 - a. Maintain as part of the laboratory quality assurance program a set of reference slides to be used on a daily basis [13]. These slides should consist of filter preparations including a range of loadings and background dust levels from a variety of sources including both field and reference samples (e.g., PAT, AAR, commercial samples). The Quality Assurance Officer

should maintain custody of the reference slides and should supply each counter with a minimum of one reference slide per workday. Change the labels on the reference slides periodically so that the counter does not become familiar with the samples.

- b. From blind repeat counts on reference slides, estimate the laboratory intra- and intercounter precision. Obtain separate values of relative standard deviation (S_r) for each sample matrix analyzed in each of the following ranges: 5 to 20 fibers in 100 graticule fields, >20 to 50 fibers in 100 graticule fields, and >50 to 100 fibers in 100 graticule fields. Maintain control charts for each of these data files.

NOTE: Certain sample matrices (e.g., asbestos cement) have been shown to give poor precision [9]

12. Prepare and count field blanks along with the field samples. Report counts on each field blank.

NOTE 1: The identity of blank filters should be unknown to the counter until all counts have been completed.

NOTE 2: If a field blank yields greater than 7 fibers per 100 graticule fields, report possible contamination of the samples.

13. Perform blind recounts by the same counter on 10% of filters counted (slides relabeled by a person other than the counter). Use the following test to determine whether a pair of counts by the same counter on the same filter should be rejected because of possible bias: Discard the sample if the absolute value of the difference between the square roots of the two counts (in fiber/mm²) exceeds $2.77 (X) S_r$, where X = average of the square roots of the two fiber counts

(in fiber/mm²) and $S_r = \frac{S_r}{2}$, where S_r is the intracounter relative standard deviation for the

appropriate count range (in fibers) determined in step 11. For more complete discussions see reference [13].

NOTE 1: Since fiber counting is the measurement of randomly placed fibers which may be described by a Poisson distribution, a square root transformation of the fiber count data will result in approximately normally distributed data [13].

NOTE 2: If a pair of counts is rejected by this test, recount the remaining samples in the set and test the new counts against the first counts. Discard all rejected paired counts. It is not necessary to use this statistic on blank counts.

14. The analyst is a critical part of this analytical procedure. Care must be taken to provide a non-stressful and comfortable environment for fiber counting. An ergonomically designed chair should be used, with the microscope eyepiece situated at a comfortable height for viewing. External lighting should be set at a level similar to the illumination level in the microscope to reduce eye fatigue. In addition, counters should take 10-to-20 minute breaks from the microscope every one or two hours to limit fatigue [14]. During these breaks, both eye and upper back/neck exercises should be performed to relieve strain.
15. All laboratories engaged in asbestos counting should participate in a proficiency testing program such as the AIHA-NIOSH Proficiency Analytical Testing (PAT) Program for asbestos and routinely exchange field samples with other laboratories to compare performance of counters.

MEASUREMENT:

16. Center the slide on the stage of the calibrated microscope under the objective lens. Focus the microscope on the plane of the filter.

17. Adjust the microscope (Step 10).

NOTE: Calibration with the HSE/NPL test slide determines the minimum detectable fiber diameter (ca. 0.25 μ m) [4].

18. Counting rules: (same as P&CAM 239 rules [1,10,11]: see examples in APPENDIX B).

- a. Count any fiber longer than 5 μ m which lies entirely within the graticule area.

(1) Count only fibers longer than 5 μ m. Measure length of curved fibers along the curve.

(2) Count only fibers with a length-to-width ratio equal to or greater than 3:1.

- b. For fibers which cross the boundary of the graticule field:

(1) Count as 1/2 fiber any fiber with only one end lying within the graticule area, provided that the fiber meets the criteria of rule a above.

- (2) Do not count any fiber which crosses the graticule boundary more than once.
 - (3) Reject and do not count all other fibers.
 - c. Count bundles of fibers as one fiber unless individual fibers can be identified by observing both ends of a fiber.
 - d. Count enough graticule fields to yield 100 fibers. Count a minimum of 20 fields. Stop at 100 graticule fields regardless of count.
19. Start counting from the tip of the filter wedge and progress along a radial line to the outer edge. Shift up or down on the filter, and continue in the reverse direction. Select graticule fields randomly by looking away from the eyepiece briefly while advancing the mechanical stage. Ensure that, as a minimum, each analysis covers one radial line from the filter center to the outer edge of the filter. When an agglomerate or bubble covers ca. 1/6 or more of the graticule field, reject the graticule field and select another. Do not report rejected graticule fields in the total number counted.
- NOTE 1: When counting a graticule field, continuously scan a range of focal planes by moving the fine focus knob to detect very fine fibers which have become embedded in the filter. The small-diameter fibers will be very faint but are an important contribution to the total count. A minimum counting time of 15 seconds per field is appropriate for accurate counting.
- NOTE 2: This method does not allow for differentiation of fibers based on morphology. Although some experienced counters are capable of selectively counting only fibers which appear to be asbestiform, there is presently no accepted method for ensuring uniformity of judgment between laboratories. It is, therefore, incumbent upon all laboratories using this method to report total fiber counts. If serious contamination from non-asbestos fibers occurs in samples, other techniques such as transmission electron microscopy must be used to identify the asbestos fiber fraction present in the sample (see NIOSH Method 7402). In some cases (i.e., for fibers with diameters >1 µm), polarized light microscopy (as in NIOSH Method 7403) may be used to identify and eliminate interfering non-crystalline fibers [15].
- NOTE 3: Do not count at edges where filter was cut. Move in at least 1 mm from the edge.
- NOTE 4: Under certain conditions, electrostatic charge may affect the sampling of fibers. These electrostatic effects are most likely to occur when the relative humidity is low (below 20%), and when sampling is performed near the source of aerosol. The result is that deposition of fibers on the filter is reduced, especially near the edge of the filter. If such a pattern is noted during fiber counting, choose fields as close to the center of the filter as possible [5].
- NOTE 5: Counts are to be recorded on a data sheet that provides, as a minimum, spaces on which to record the counts for each field, filter identification number, analyst's name, date, total fibers counted, total fields counted, average count, fiber density, and commentary. Average count is calculated by dividing the total fiber count by the number of fields observed. Fiber density (fibers/mm²) is defined as the average count (fibers/field) divided by the field (graticule) area (mm²/field).

CALCULATIONS AND REPORTING OF RESULTS

20. Calculate and report fiber density on the filter, E (fibers/mm²), by dividing the average fiber count per graticule field, F/n_f , minus the mean field blank count per graticule field, B/n_b , by the graticule field area, A_f (approx. 0.00785 mm²):

$$E = \frac{\left(\frac{F}{n_f} - \frac{B}{n_b} \right)}{A_f}, \text{ fibers/mm}^2.$$

NOTE: Fiber counts above 1300 fibers/mm² and fiber counts from samples with >50% of filter area covered with particulate should be reported as "uncountable" or "probably biased." Other fiber counts outside the 100-1300 fiber/mm² range should be reported as having "greater than optimal variability" and as being "probably biased."

21. Calculate and report the concentration, C (fibers/cc), of fibers in the air volume sampled, V (L), using the effective collection area of the filter, A_c (approx. 385 mm² for a 25-mm filter):

$$C = \frac{(E)(A_c)}{V \cdot 10^3}$$

NOTE: Periodically check and adjust the value of A_c, if necessary.

22. Report intralaboratory and interlaboratory relative standard deviations (from Step 11) with each set of results.

NOTE: Precision depends on the total number of fibers counted [1,16]. Relative standard deviation is documented in references [1,15-17] for fiber counts up to 100 fibers in 100 graticule fields. Comparability of interlaboratory results is discussed below. As a first approximation, use 213% above and 49% below the count as the upper and lower confidence limits for fiber counts greater than 20 (Fig. 1).

EVALUATION OF METHOD:

- A. This method is a revision of P&CAM 239 [10]. A summary of the revisions is as follows:

1. Sampling:

The change from a 37-mm to a 25-mm filter improves sensitivity for similar air volumes. The change in flow rates allows for 2-m³ full-shift samples to be taken, providing that the filter is not overloaded with non-fibrous particulates. The collection efficiency of the sampler is not a function of flow rate in the range 0.5 to 16 L/min [10].

2. Sample Preparation Technique:

The acetone vapor-triacetin preparation technique is a faster, more permanent mounting technique than the dimethyl phthalate/diethyl oxalate method of P&CAM 239 [2,4,10]. The aluminum "hot block" technique minimizes the amount of acetone needed to prepare each sample.

3. Measurement:

- a. The Walton-Beckett graticule standardizes the area observed [14,18,19].
- b. The HSE/NPL test slide standardizes microscope optics for sensitivity to fiber diameter [4,14].
- c. Because of past inaccuracies associated with low fiber counts, the minimum recommended loading has been increased to 100 fibers/mm² filter area (a total of 78.5 fibers counted in 100 fields, each with field area = .00785 mm².) Lower levels generally result in an overestimate of the fiber count when compared to results in the recommended analytical range [20]. The recommended loadings should yield intracounter S_r in the range of 0.10 to 0.17 [21,22,23].

- B. Interlaboratory comparability:

An international collaborative study involved 16 laboratories using prepared slides from the asbestos cement, milling, mining, textile, and friction material industries [9]. The relative standard deviations (S_r) varied with sample type and laboratory. The ranges were:

	<u>Intralaboratory S_r</u>	<u>Interlaboratory S_r</u>	<u>Overall S_r</u>
AIA (NIOSH A Rules)*	0.12 to 0.40	0.27 to 0.85	0.46
Modified CRS (NIOSH B Rules)**	0.11 to 0.29	0.20 to 0.35	0.25

* Under AIA rules, only fibers having a diameter less than 3 µm are counted and fibers attached to particles larger than 3 µm are not counted. NIOSH A Rules are otherwise similar to the AIA rules.

** See Appendix C.

A NIOSH study conducted using field samples of asbestos gave intralaboratory S_r in the range 0.17 to 0.25 and an interlaboratory S_r of 0.45 [21]. This agrees well with other recent studies [9,14,16].

At this time, there is no independent means for assessing the overall accuracy of this method. One measure of reliability is to estimate how well the count for a single sample agrees with the mean count from a large number of laboratories. The following discussion indicates how this estimation can be carried out based on measurements of the interlaboratory variability, as well as showing how the results of this method relate to the theoretically attainable counting precision and to measured intra- and interlaboratory S_r. (NOTE: The following discussion does not include bias estimates and should not be taken to indicate that lightly loaded samples are as accurate as properly loaded ones).

Theoretically, the process of counting randomly (Poisson) distributed fibers on a filter surface will give an S_r that depends on the number, N, of fibers counted:

$$S_r = 1/(N)^{1/2} \quad (1)$$

Thus S_r is 0.1 for 100 fibers and 0.32 for 10 fibers counted. The actual S_r found in a number of studies is greater than these theoretical numbers [17,19,20,21].

An additional component of variability comes primarily from subjective interlaboratory differences. In a study of ten counters in a continuing sample exchange program, Ogden [15] found this subjective component of intralaboratory S_r to be approximately 0.2 and estimated the overall S_r by the term:

$$\frac{[N + (0.2 \cdot N)^2]^{1/2}}{N} \quad (2)$$

Ogden found that the 90% confidence interval of the individual intralaboratory counts in relation to the means were +2 S_r and -1.5 S_r. In this program, one sample out of ten was a quality control sample. For laboratories not engaged in an intensive quality assurance program, the subjective component of variability can be higher.

In a study of field sample results in 46 laboratories, the Asbestos Information Association also found that the variability had both a constant component and one that depended on the fiber count [14]. These results gave a subjective interlaboratory component of S_r (on the same basis as Ogden's) for field samples of ca. 0.45. A similar value was obtained for 12 laboratories analyzing a set of 24 field samples [21]. This value falls slightly above the range of S_r (0.25 to 0.42 for 1984-85) found for 80 reference laboratories in the NIOSH PAT program for laboratory-generated samples [17].

A number of factors influence S_r for a given laboratory, such as that laboratory's actual counting performance and the type of samples being analyzed. In the absence of other information, such as from an interlaboratory quality assurance program using field samples, the value for the subjective component of variability is chosen as 0.45. It is hoped that the laboratories will carry out the recommended interlaboratory quality assurance programs to improve their performance and thus reduce the S_r.

The above relative standard deviations apply when the population mean has been determined. It is more useful, however, for laboratories to estimate the 90% confidence interval on the mean count from a single sample fiber count (Figure 1). These curves assume similar shapes of the count distribution for interlaboratory and intralaboratory results [16].

For example, if a sample yields a count of 24 fibers, Figure 1 indicates that the mean interlaboratory count will fall within the range of 227% above and 52% below that value 90% of the time. We can apply these percentages directly to the air concentrations as well. If, for instance, this sample (24 fibers counted) represented a 500-L volume, then the measured concentration is 0.02 fibers/mL (assuming 100 fields counted, 25-mm filter, 0.00785 mm² counting field area). If this same sample were counted by a group of laboratories, there is a 90% probability that the mean would fall between 0.01 and 0.08 fiber/mL. These limits should be reported in any comparison of results between laboratories.

Note that the S_r of 0.45 used to derive Figure 1 is used as an estimate for a random group of laboratories. If several laboratories belonging to a quality assurance group can show that their interlaboratory S_r is smaller, then it is more correct to use that smaller S_r . However, the estimated S_r of 0.45 is to be used in the absence of such information. Note also that it has been found that S_r can be higher for certain types of samples, such as asbestos cement [9].

Quite often the estimated airborne concentration from an asbestos analysis is used to compare to a regulatory standard. For instance, if one is trying to show compliance with an 0.5 fiber/mL standard using a single sample on which 100 fibers have been counted, then Figure 1 indicates that the 0.5 fiber/mL standard must be 213% higher than the measured air concentration. This indicates that if one measures a fiber concentration of 0.16 fiber/mL (100 fibers counted), then the mean fiber count by a group of laboratories (of which the compliance laboratory might be one) has a 95% chance of being less than 0.5 fibers/mL; i.e., $0.16 + 2.13 \times 0.16 = 0.5$.

It can be seen from Figure 1 that the Poisson component of the variability is not very important unless the number of fibers counted is small. Therefore, a further approximation is to simply use +213% and -49% as the upper and lower confidence values of the mean for a 100-fiber count.

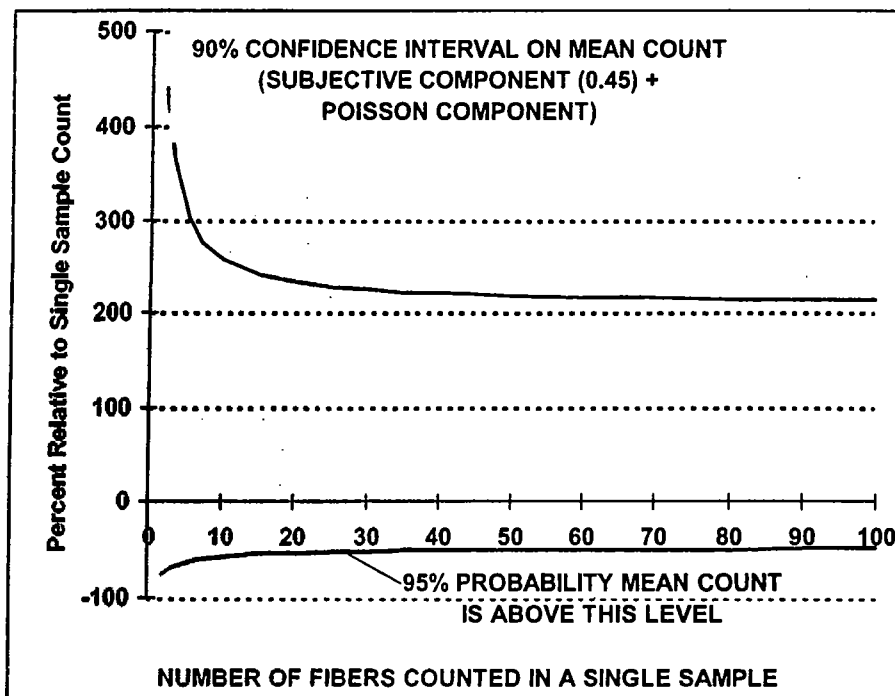


Figure 1. Interlaboratory Precision of Fiber Counts

The curves in Figures 1 are defined by the following equations:

$$\text{UCL} = \frac{2X + 2.25 + [(2.25 + 2X)^2 - 4(1 - 2.25S_r^2)X^2]^{1/2}}{2(1 - 2.25S_r^2)} \quad (3)$$

$$\text{LCL} = \frac{2X + 4 - [(4 + 2X)^2 - 4(1 - 4S_r^2)X^2]^{1/2}}{2(1 - 4S_r^2)} \quad (4)$$

where S_r = subjective interlaboratory relative standard deviation, which is close to the total interlaboratory S_r when approximately 100 fibers are counted.

X = total fibers counted on sample

LCL = lower 95% confidence limit.

UCL = upper 95% confidence limit.

Note that the range between these two limits represents 90% of the total range.

REFERENCES:

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METHOD WRITTEN BY:

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APPENDIX A: CALIBRATION OF THE WALTON-BECKETT GRATICULE:

Before ordering the Walton-Beckett graticule, the following calibration must be done to obtain a counting area (D) 100 μm in diameter at the image plane. The diameter, d_c (mm), of the circular counting area and the disc diameter must be specified when ordering the graticule.

1. Insert any available graticule into the eyepiece and focus so that the graticule lines are sharp and clear.
2. Set the appropriate interpupillary distance and, if applicable, reset the binocular head adjustment so that the magnification remains constant.
3. Install the 40 to 45X phase objective.
4. Place a stage micrometer on the microscope object stage and focus the microscope on the graduated lines.
5. Measure the magnified grid length of the graticule, L_o (μm), using the stage micrometer.
6. Remove the graticule from the microscope and measure its actual grid length, L_a (mm). This can best be accomplished by using a stage fitted with verniers.
7. Calculate the circle diameter, d_c (mm), for the Walton-Beckett graticule:

$$d_c = \frac{L_s}{L_o} \times D.$$

(5)

Example: If $L_o = 112 \mu\text{m}$, $L_s = 4.5 \text{ mm}$ and $D = 100 \mu\text{m}$, then $d_c = 4.02 \text{ mm}$.

8. Check the field diameter, D (acceptable range $100 \mu\text{m} \pm 2 \mu\text{m}$) with a stage micrometer upon receipt of the graticule from the manufacturer. Determine field area (acceptable range 0.00754 mm^2 to 0.00817 mm^2).

APPENDIX B: COMPARISON OF COUNTING RULES:

Figure 2 shows a Walton-Beckett graticule as seen through the microscope. The rules will be discussed as they apply to the labeled objects in the figure.

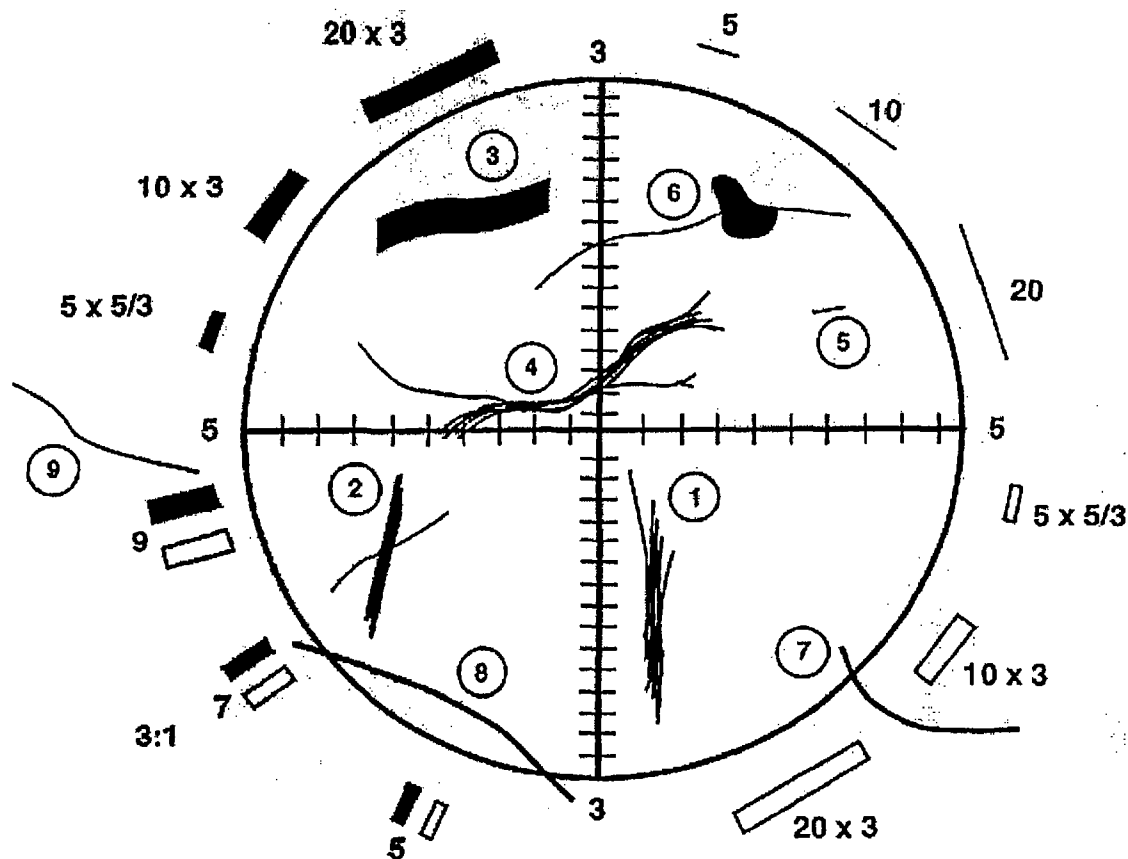


Figure 2. Walton-Beckett graticule with fibers.

These rules are sometimes referred to as the "A" rules.

FIBER COUNT

<u>Object</u>	<u>Count</u>	<u>DISCUSSION</u>
1	1 fiber	Optically observable asbestos fibers are actually bundles of fine fibrils. If the fibrils seem to be from the same bundle the object is counted as a single fiber. Note, however, that all objects meeting length and aspect ratio criteria are counted whether or not they appear to be asbestos.
2	2 fiber	If fibers meeting the length and aspect ratio criteria (length $>5\ \mu\text{m}$ and length-to-width ratio >3 to 1) overlap, but do not seem to be part of the same bundle, they are counted as separate fibers.
3	1 fiber	Although the object has a relatively large diameter ($>3\ \mu\text{m}$), it is counted as fiber under the rules. There is no upper limit on the fiber diameter in the counting rules. Note that fiber width is measured at the widest compact section of the object.
4	1 fiber	Although long fine fibrils may extend from the body of a fiber, these fibrils are considered part of the fiber if they seem to have originally been part of the bundle.
5	Do not count	If the object is $\leq 5\ \mu\text{m}$ long, it is not counted.
6	1 fiber	A fiber partially obscured by a particle is counted as one fiber. If the fiber ends emanating from a particle do not seem to be from the same fiber and each end meets the length and aspect ratio criteria, they are counted as separate fibers.
7	1/2 fiber	A fiber which crosses into the graticule area one time is counted as 1/2 fiber.
8	Do not count	Ignore fibers that cross the graticulate boundary more than once.
9	Do not count	Ignore fibers that lie outside the graticule boundary.

APPENDIX C. ALTERNATE COUNTING RULES FOR NON-ASBESTOS FIBERS

Other counting rules may be more appropriate for measurement of specific non-asbestos fiber types, such as fibrous glass. These include the "B" rules given below (from NIOSH Method 7400, Revision #2, dated 8/15/87), the World Health Organization reference method for man-made mineral fiber [24], and the NIOSH fibrous glass criteria document method [25]. The upper diameter limit in these methods prevents measurements of non-thoracic fibers. It is important to note that the aspect ratio limits included in these methods vary. NIOSH recommends the use of the 3:1 aspect ratio in counting fibers.

It is emphasized that hybridization of different sets of counting rules is not permitted. Report specifically which set of counting rules are used with the analytical results.

"B" COUNTING RULES:

1. Count only ends of fibers. Each fiber must be longer than 5 μm and less than 3 μm diameter.
2. Count only ends of fibers with a length-to-width ratio equal to or greater than 5:1.
3. Count each fiber end which falls within the graticule area as one end, provided that the fiber meets rules 1 and 2 above. Add split ends to the count as appropriate if the split fiber segment also meets the criteria of rules 1 and 2 above.
4. Count visibly free ends which meet rules 1 and 2 above when the fiber appears to be attached to another particle, regardless of the size of the other particle. Count the end of a fiber obscured by another particle if the particle covering the fiber end is less than 3 μm in diameter.
5. Count free ends of fibers emanating from large clumps and bundles up to a maximum of 10 ends (5 fibers), provided that each segment meets rules 1 and 2 above.
6. Count enough graticule fields to yield 200 ends. Count a minimum of 20 graticule fields. Stop at 100 graticule fields, regardless of count.
7. Divide total end count by 2 to yield fiber count.

APPENDIX D. EQUIVALENT LIMITS OF DETECTION AND QUANTITATION

<u>fiber density on filter*</u>		<u>fiber concentration in air, f/cc</u>	
<u>fibers</u>		<u>400-L air</u>	<u>1000-L air</u>
<u>per 100 fields</u>	<u>fibers/mm²</u>	<u>sample</u>	<u>sample</u>
200	255	0.25	0.10
100	127	0.125	0.05
LOQ 80	102	0.10	0.04
50	64	0.0625	0.025
25	32	0.03	0.0125
20	25	0.025	0.010
10	12.7	0.0125	0.005
8	10.2	0.010	0.004
LOD 5.5	7	0.00675	0.0027

* Assumes 385 mm² effective filter collection area, and field area = 0.00785 mm², for relatively "clean" (little particulate aside from fibers) filters.

ASBESTOS by TEM

7402

FORMULA: Various

MW: Various

CAS: Various

RTECS: Various

METHOD: 7402

EVALUATION: PARTIAL

Issue 1: 15 May 1989

Issue 2: 15 August 1994

OSHA : 0.1 asbestos fibers (>5 µm long)/cc;
1 f/cc/30 min excursion; carcinogen
MSHA: 2 asbestos fibers/cc
NIOSH: 0.1 f/cc (fibers > 5 µm long)/400 L; carcinogen
ACGIH: 0.2 crocidolite; 0.5 amosite; 2 chrysotile
and other asbestos, fibers/cc; carcinogen

PROPERTIES: solid, fibrous, crystalline,
anisotropic

SYNONYMS [CAS#]: actinolite [77536-66-4] or ferroactinolite [15669-07-5]; amosite [12172-73-5]; anthophyllite [77536-67-5]; chrysotile [12001-29-5]; serpentine [18786-24-8]; crocidolite [12001-28-4]; tremolite [77536-68-6]; amphibole asbestos [1332-21-4].

SAMPLING		MEASUREMENT	
SAMPLER: FILTER (0.45- to 1.2-µm cellulose ester membrane, 25-mm diameter; conductive cassette) FLOW RATE: 0.5 to 16 L/min VOL-MIN*: 400 L @ 0.1 fiber/cc -MAX*: (step 4, sampling) *Adjust for 100 to 1300 fibers/mm ² SHIPMENT: routine (pack to reduce shock) SAMPLE STABILITY: stable BLANKS: 2 to 10 field blanks per set		TECHNIQUE:	MICROSCOPY, TRANSMISSION ELECTRON (TEM)
		ANALYTE:	asbestos fibers
		SAMPLE PREPARATION:	modified Jaffe wick
		EQUIPMENT:	transmission electron microscope; energy dispersive X-ray system (EDX) analyzer
		CALIBRATION:	qualitative electron diffraction; calibration of TEM magnification and EDX system
ACCURACY RANGE STUDIED: 80 to 100 fibers counted BIAS: not determined OVERALL PRECISION (\bar{S}_r): see EVALUATION OF METHOD ACCURACY: not determined		RANGE:	100 to 1300 fibers/mm ² filter area [1]
		ESTIMATED LOD:	1 confirmed asbestos fiber above 95% of expected mean blank value
		PRECISION (\bar{S}_r):	0.28 when 65% of fibers are asbestos; 0.20 when adjusted fiber count is applied to PCM count [2].

APPLICABILITY: The quantitative working range is 0.04 to 0.5 fiber/cc for a 1000-L air sample. The LOD depends on sample volume and quantity of interfering dust, and is <0.01 fiber/cc for atmospheres free of interferences. This method is used to determine asbestos fibers in the optically visible range and is intended to complement the results obtained by phase contrast microscopy (Method 7400).

INTERFERENCES: Other amphibole particles that have aspect ratios greater than 3:1 and elemental compositions similar to the asbestos minerals may interfere in the TEM analysis. Some non-amphibole minerals may give electron diffraction patterns similar to amphiboles. High concentrations of background dust interfere with fiber identification. Some non-asbestos amphibole minerals may give electron diffraction patterns similar to asbestos amphiboles.

OTHER METHODS: This method is designed for use with Method 7400 (phase contrast microscopy).

REAGENTS:

1. Acetone. (See SPECIAL PRECAUTIONS.)

EQUIPMENT:

1. Sampler: field monitor, 25-mm, three-piece cassette with ca. 50-mm electrically-conductive extension cowl, cellulose ester membrane filter, 0.45- to 1.2- μ m pore size, and backup pad.
NOTE 1: Analyze representative filters for fiber background before use. Discard the filter lot if mean count is >5 fibers/100 fields. These are defined as laboratory blanks.
NOTE 2: Use an electrically-conductive extension cowl to reduce electrostatic effects on fiber sampling and during sample shipment. Ground the cowl when possible during sampling.
NOTE 3: 0.8- μ m pore size filters are recommended for personal sampling. 0.45- μ m filters are recommended for sampling when performing TEM analysis on the samples because the particles deposit closer to the filter surface. However, the higher pressure drop through these filters normally preclude their use with personal sampling pumps.
2. Personal sampling pump, 0.5 to 16 L/min, with flexible connecting tubing.
3. Microscope, transmission electron, operated at ca. 100 kV, with electron diffraction and energy-dispersive X-ray capabilities, and having a fluorescent screen with inscribed or overlaid calibrated scale (Step 15).
NOTE: The scale is most efficient if it consists of a series of lines inscribed on the screen or partial circles every 2 cm distant from the center.
4. Diffraction grating replica with known number of lines/mm.
5. Slides, glass, pre-cleaned, 25- x 75-mm.
6. Knife, surgical steel, curved-blade.
7. Tweezers.
8. Grids, 200-mesh TEM copper, (optional: carbon-coated).
9. Petri dishes, 15-mm depth. The top and bottom of the petri dish must fit snugly together. To assure a tight fit, grind the top and bottom pieces together with an abrasive such as carborundum to produce a ground-glass contact surface.
10. Foam, clean polyurethane, spongy, 12-mm thick.
11. Filters, Whatman No. 1 qualitative paper or equivalent, or lens paper.
12. Vacuum evaporator.
13. Cork borer, (about 8-mm).
14. Pen, waterproof, marking.
15. Reinforcement, page, gummed.
16. Asbestos standard bulk materials for reference; e.g. SRM #1866, available from the National Institute of Standards and Technology.
17. Carbon rods, sharpened to 1 mm x 8 mm.
18. Microscope, light, phase contrast (PCM), with Walton-Beckett graticule (see method 7400).
19. Grounding wire, 22-gauge, multi-strand.
20. Tape, shrink- or adhesive-.

SPECIAL PRECAUTIONS: Acetone is extremely flammable (flash point = 0 °F). Take precautions not to ignite it. Heating of acetone must be done in a fume hood using a flameless, spark-free heat source. Asbestos is a confirmed human carcinogen. Handle only in a well-ventilated fume hood.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. For personal sampling, fasten sampler to worker's lapel near worker's mouth. Remove the top cover from cowl extension ("open-face") and orient sampler face down. Wrap joint between extender and monitor body with tape to help hold the cassette together and provide a marking surface to identify the cassette. Where possible, especially at low %RH, attach sampler to electrical ground to reduce electrostatic effects during sampling.
3. Submit at least two field blanks (or 10% of the total samples, whichever is greater) for each set of samples. Remove top covers from the field blank cassettes and store top covers and cassettes in a clean area (e.g., closed bag or box) during sampling. Replace top covers when sampling is completed.
4. Sample at 0.5 to 16 L/min [3]. Adjust sampling rate, Q (L/min), and time, t (min), to produce fiber density, E, of 100 to 1300 fibers/mm² [$3.85 \cdot 10^4$ to $5 \cdot 10^5$ fibers per 25-mm filter with effective collection area ($A_c = 385 \text{ mm}^2$)] for optimum accuracy. Do not exceed ca. 0.5 mg total dust loading on the filter. These variables are related to the action level (one-half the current standard), L (fibers/cc), of the fibrous aerosol being sampled by:

$$t = \frac{A_c \cdot E}{Q \cdot L \cdot 10^3}, \text{ min.}$$

NOTE: The purpose of adjusting sampling times is to obtain optimum fiber loading on the filter. A sampling rate of 1 to 4 L/min for 8 h (700 to 2800 L) is appropriate in atmospheres containing ca. 0.1 fiber/cc in the absence of significant amounts of non-asbestos dust. Dusty atmospheres require smaller sample volumes ($\leq 400 \text{ L}$) to obtain countable samples. In such cases take short, consecutive samples and average the results over the total collection time. For documenting episodic exposures, use high rates (7 to 16 L/min) over shorter sampling times. In relatively clean atmospheres, where targeted fiber concentrations are much less than 0.1 fiber/cc, use larger sample volumes (3000 to 10000 L) to achieve quantifiable loadings. Take care, however, not to overload the filter with background dust [3].

5. At the end of sampling, replace top cover and small end caps.
6. Ship samples upright with conductive cowl attached in a rigid container with packing material to prevent jostling or damage.

NOTE: Do not use untreated polystyrene foam in the shipping container because electrostatic forces may cause fiber loss from sample filter.

SAMPLE PREPARATION:

7. Remove circular sections from any of three quadrants of each sample and blank filter using a cork borer [4]. The use of three grid preparations reduces the effect of local variations in dust deposit on the filter.
8. Affix the circular filter sections to a clean glass slide with a gummed page reinforcement. Label the slide with a waterproof marking pen.
NOTE: Up to eight filter sections may be attached to the same slide.
9. Place the slide in a petri dish which contains several paper filters soaked with 2 to 3 mL acetone. Cover the dish. Wait 2 to 4 min for the sample filter(s) to fuse and clear.
NOTE: The "hot block" clearing technique [5] of Method 7400 or the DMF clearing technique [6] may be used instead of steps 8 and 9.
10. Transfer the slide to a rotating stage inside the bell jar of a vacuum evaporator. Evaporate a 1-by 5-mm section of a graphite rod onto the cleared filter(s). Remove the slide to a clean, dry, covered petri dish [4].
11. Prepare a second petri dish as a Jaffe wick washer with the wicking substrate prepared from filter or lens paper placed on top of a 12-mm thick disk of clean, spongy polyurethane foam [7].

Cut a V-notch on the edge of the foam and filter paper. Use the V-notch as a reservoir for adding solvent.

NOTE: The wicking substrate should be thin enough to fit into the petri dish without touching the lid.

12. Place the TEM grid on the filter or lens paper. Label the grids by marking with a pencil on the filter paper or by putting registration marks on the petri dish halves and marking with a waterproof marker on the dish lid. In a fume hood, fill the dish with acetone until the wicking substrate is saturated.
NOTE: The level of acetone should be just high enough to saturate the filter paper without creating puddles.
13. Remove about a quarter section of the carbon-coated filter from the glass slide using a surgical knife and tweezers. Carefully place the excised filter, carbon side down, on the appropriately-labeled grid in the acetone-saturated petri dish. When all filter sections have been transferred, slowly add more solvent to the wedge-shaped trough to raise the acetone level as high as possible without disturbing the sample preparations. Cover the petri dish. Elevate one side of the petri dish by placing a slide under it (allowing drops of condensed acetone to form near the edge rather than in the center where they would drip onto the grid preparation).

CALIBRATION AND QUALITY CONTROL:

14. Determine the TEM magnification on the fluorescent screen:
 - a. Define a field of view on the fluorescent screen either by markings or physical boundaries.
NOTE: The field of view must be measurable or previously inscribed with a scale or concentric circles (all scales should be metric) [7].
 - b. Insert a diffraction grating replica into the specimen holder and place into the microscope. Orient the replica so that the grating lines fall perpendicular to the scale on the TEM fluorescent screen. Ensure that goniometer stage tilt is zero.
 - c. Adjust microscope magnification to 10,000X. Measure the distance (mm) between the same relative positions (e.g., between left edges) of two widely-separated lines on the grating replica. Count the number of spaces between the lines.
NOTE: On most microscopes the magnification is substantially constant only within the central 8- to 10-cm diameter region of the fluorescent screen.
 - d. Calculate the true magnification (M) on the fluorescent screen:

$$m = \frac{X \cdot G}{Y}$$

where: X = total distance (mm) between the two grating lines;
G = calibration constant of the grating replica (lines/mm);
Y = number of grating replica spaces counted

- e. After calibration, note the apparent sizes of 0.25 and 5.0 μm on the fluorescent screen. (These dimensions are the boundary limits for counting asbestos fibers by phase contrast microscopy.)
15. Measure 20 grid openings at random on a 200-mesh copper grid by placing a grid on a glass slide and examining it under the PCM. Use the Walton-Beckett graticule to measure the grid opening dimensions. Calculate an average graticule field dimension from the data and use this number to calculate the graticule field area for an average grid opening.
NOTE: A grid opening is considered as one graticule field.
16. Obtain reference selected area electron diffraction (SAED) or microdiffraction patterns from standard asbestos materials prepared for TEM analysis.
NOTE: This is a visual reference technique. No quantitative SAED analysis is required [7]. Microdiffraction may produce clearer patterns on very small fibers or fibers partially obscured by other material.
 - a. Set the specimen holder at zero tilt.

- b. Center a fiber, focus, and center the smallest field-limiting aperture on the fiber. Obtain a diffraction pattern. Photograph each distinctive pattern and keep the photo for comparison to unknowns.
 NOTE: Not all fibers will present diffraction patterns. The objective lens current may need adjustment to give optimum pattern visibility. There are many more amphiboles which give diffraction patterns similar to the analytes named on p. 7402-1. Some, but not all, of these can be eliminated by chemical separations. Also, some non-amphiboles (e.g., pyroxenes, some talc fibers) may interfere.
17. Acquire energy-dispersive X-ray (EDX) spectra on approximately 5 fibers having diameters between 0.25 and 0.5 μm of each asbestos variety obtained from standard reference materials [7].
 NOTE: The sample may require tilting to obtain adequate signal. Use same tilt angle for all spectra.
 - a. Prepare TEM grids of all asbestos varieties.
 - b. Use acquisition times (at least 100 sec) sufficient to show a silicon peak at least 75% of the monitor screen height at a vertical scale of ≥ 500 counts per channel.
 - c. Estimate the elemental peak heights visually as follows:
 - (1) Normalize all peaks to silicon (assigned an arbitrary value of 10).
 - (2) Visually interpret all other peaks present and assign values relative to the silicon peak.
 - (3) Determine an elemental profile for the fiber using the elements Na, Mg, Si, Ca, and Fe. Example: 0-4-10-3-<1 [7].
 NOTE: In fibers other than asbestos, determination of Al, K, Ti, S, P, and F may also be required for fiber characterization.
 - (4) Determine a typical range of profiles for each asbestos variety and record the profiles for comparison to unknowns.

MEASUREMENT:

18. Perform a diffraction pattern inspection on all sample fibers counted under the TEM, using the procedures given in step 17. Assign the diffraction pattern to one of the following structures:
 - a. chrysotile;
 - b. amphibole;
 - c. ambiguous;
 - d. none.
 NOTE: There are some crystalline substances which exhibit diffraction patterns similar to those of asbestos fibers. Many of these, (brucite, halloysite, etc.) can be eliminated from consideration by chemistry. There are, however, several minerals (e.g., pyroxenes, massive amphiboles, and talc fibers) which are chemically similar to asbestos and can be considered interferences. The presence of these substances may warrant the use of more powerful diffraction pattern analysis before positive identification can be made. If interferences are suspected, morphology can play an important role in making positive identification.
19. Obtain EDX spectra in either the TEM or STEM modes from fibers on field samples using the procedure of step 18. Using the diffraction pattern and EDX spectrum, classify the fiber:
 - a. For a chrysotile structure, obtain EDX spectra on the first five fibers and one out of ten thereafter. Label the range profiles from 0-5-10-0-0 to 0-10-10-0-0 as "chrysotile."
 - b. For an amphibole structure, obtain EDX spectra on the first 10 fibers and one out of ten thereafter. Label profiles ca. 0-2-10-0-7 as "possible amosite"; profiles ca. 1-1-10-0-6 as "possible crocidolite"; profiles ca. 0-4-10-3-<1 as "possible tremolite"; and profiles ca. 0-3-10-0-1 as "possible anthophyllite."
 NOTE: The range of profiles for the amphiboles will vary up to ± 1 unit for each of the elements present according to the relative detector efficiency of the spectrometer.
 - c. For an ambiguous structure, obtain EDX spectra on all fibers. Label profiles similar to the chrysotile profile as "possible chrysotile." Label profiles similar to the various amphiboles as "possible amphiboles." Label all others as "unknown" or "non-asbestos."

20. Counting and Sizing:

- a. Insert the sample grid into the specimen grid holder and scan the grid at zero tilt at low magnification (ca. 300 to 500X). Ensure that the carbon film is intact and unbroken over ca. 75% of the grid openings.
- b. In order to determine how the grids should be sampled, estimate the number of fibers per grid opening during a low-magnification scan (500 to 1000X). This will allow the analyst to cover most of the area of the grids during the fiber count and analysis. Use the following rules when picking grid openings to count [7,8]:
 - (1) Light loading (<5 fibers per grid opening): count total of 40 grid openings.
 - (2) Moderate loading (5 to 25 fibers per grid opening): count minimum of 40 grid openings or 100 fibers.
 - (3) Heavy loading (>25 fibers per opening): count a minimum of 100 fibers and at least 6 grid openings.

Note that these grid openings should be selected approximately equally among the three grid preparations and as randomly as possible from each grid.

- c. Count only grid openings that have the carbon film intact. At 500 to 1000X magnification, begin counting at one end of the grid and systematically traverse the grid by rows, reversing direction at row ends. Select the number of fields per traverse based on the loading indicated in the initial scan. Count at least 2 field blanks per sample set to document possible contamination of the samples. Count fibers using the following rules:
 - (1) Count all particles with diameter greater than 0.25 μm that meet the definition of a fiber (aspect ratio $\geq 3:1$, longer than 5 μm). Use the guideline of counting all fibers that would have been counted under phase contrast light microscopy (Method 7400). Use higher magnification (10000X) to determine fiber dimensions and countability under the acceptance criteria. Analyze a minimum of 10% of the fibers, and at least 3 asbestos fibers, by EDX and SAED to confirm the presence of asbestos. Fibers of similar morphology under high magnification can be identified as asbestos without SAED. Particles which are of questionable morphology should be analyzed by SAED and EDX to aid in identification.
 - (2) Count fibers which are partially obscured by the grid as half fibers.
NOTE: If a fiber is partially obscured by the grid bar at the edge of the field of view, count it as a half fiber only if more than 2.5 μm of fiber is visible.
 - (3) Size each fiber as it is counted and record the diameter and length:
 - (a) Move the fiber to the center of the screen. Read the length of the fiber directly from the scale on the screen.
NOTE 1: Data can be recorded directly off the screen in μm and later converted to μm by computer.
NOTE 2: For fibers which extend beyond the field of view, the fiber must be moved and superimposed upon the scale until its entire length has been measured.
 - (b) When a fiber has been sized, return to the lower magnification and continue the traverse of the grid area to the next fiber.
- d. Record the following fiber counts:
 - (1) f_s, f_b = number of asbestos fibers in the grid openings analyzed on the sample filter and corresponding field blank, respectively.
 - (2) F_s, F_b = number of fibers, regardless of identification, in the grid openings analyzed on the sample filter and corresponding field blank, respectively.

CALCULATIONS:

21. Calculate and report the fraction of optically visible asbestos fibers on the filter, $(f_s - f_b)/(F_s - F_b)$. Apply this fraction to fiber counts obtained by PCM on the same filter or on other filters for which the TEM sample is representative. The final result is an asbestos fiber count. The type of asbestos present should also be reported.
22. As an integral part of the report, give the model and manufacturer of the TEM as well as the model and manufacturer of the EDX system.

EVALUATION OF METHOD:

The TEM method, using the direct count of asbestos fibers, has been shown to have a precision of 0.275 (s_r) in an evaluation of mixed amosite and wollastonite fibers. The estimate of the asbestos fraction, however, had a precision of 0.11 (s_p). When this fraction was applied to the PCM count, the overall precision of the combined analysis was 0.20 [2].

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METHOD REVISED BY:

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APPENDIX B

EPA SOP 2015

ASBESTOS SAMPLING



ASBESTOS SAMPLING

SOP#: 2015
DATE: 11/17/94
REV. #: 0.0

1.0 SCOPE AND APPLICATION

Asbestos has been used in many commercial products including building materials such as flooring tiles and sheet goods, paints and coatings, insulation, and roofing asphalts. These products and others may be found at hazardous waste sites hanging on overhead pipes, contained in drums, abandoned in piles, or as part of a structure. Asbestos tailing piles from mining operations can also be a source of ambient asbestos fibers. Asbestos is a known carcinogen and requires air sampling to assess airborne exposure to human health. This Standard Operating Procedure (SOP) provides procedures for asbestos air sampling by drawing a known volume of air through a mixed cellulose ester (MCE) filter. The filter is then sent to a laboratory for analysis. The U.S. Environmental Protection Agency/Environmental Response Team (U.S. EPA/ERT) uses one of four analytical methods for determining asbestos in air. These include: U.S. EPA's Environmental Asbestos Assessment Manual, Superfund Method for the Determination of Asbestos in Ambient Air for Transmission Electron Microscopy (TEM)⁽¹⁾; U.S. EPA's Modified Yamate Method for TEM⁽²⁾; National Institute for Occupational Safety and Health (NIOSH) Method 7402 (direct method only) for TEM; and NIOSH Method 7400 for Phase Contrast Microscopy (PCM)⁽³⁾. Each method has specific sampling and analytical requirements (i.e., sample volume and flow rate) for determining asbestos in air.

The U.S. EPA/ERT typically follows procedures outlined in the TEM methods for determining mineralogical types of asbestos in air and for distinguishing asbestos from non-asbestos minerals. The Phase Contrast Microscopy (PCM) method is used by U.S. EPA/ERT as a screening tool since it is less costly than TEM. PCM cannot distinguish asbestos from non-asbestos fibers, therefore the TEM method may be necessary to confirm analytical results. For example, if an action level for the presence of fibers has been set and PCM analysis indicates that the action level has been exceeded, then

TEM analysis can be used to quantify and identify asbestos structures through examination of their morphology crystal structures (through electron diffraction), and elemental composition (through energy dispersive X-ray analysis). In this instance samples should be collected for both analyses in side by side sampling trains (some laboratories are able to perform PCM and TEM analysis from the same filter). The Superfund method is designed specifically to provide results suitable for supporting risk assessments at Superfund sites, it is applicable to a wide range of ambient air situations at hazardous waste sites. U.S. EPA's Modified Yamate Method for TEM is also used for ambient air sampling due to high volume requirements. The PCM and TEM NIOSH analytical methods require lower sample volumes and are typically used indoors; however, ERT will increase the volume requirement for outdoor application.

Other Regulations pertaining to asbestos have been promulgated by U.S. EPA and OSHA. U.S. EPA's National Emission Standards for Hazardous Air Pollutants (NESHAP) regulates asbestos-containing waste materials. NESHAP establishes management practices and standards for the handling of asbestos and emissions from waste disposal operations (40 CFR Part 61, Subparts A and M). U.S. EPA's 40 CFR 763 (July 1, 1987)⁽⁴⁾ and its addendum 40 CFR 763 (October 30, 1987)⁽⁴⁾ provide comprehensive rules for the asbestos abatement industry. State and local regulations on these issues vary and may be more stringent than federal requirements. The OSHA regulations in 29 CFR 1910.1001 and 29 CFR 1926.58 specify work practices and safety equipment such as respiratory protection and protective clothing when handling asbestos. The OSHA standard for an 8-hour, time-weighted average (TWA) is 0.2 fibers/cubic centimeters of air. This standard pertains to fibers with a length-to-width ratio of 3 to 1 with a fiber length $>5 \mu\text{m}$ ^(5,6). An action level of 0.1 fiber/cc (one-half the OSHA standard) is the level U.S. EPA has established in which employers must initiate such activities as air monitoring, employee training, and

medical surveillance^(5,6).

These are standard (i.e., typically applicable) operating procedures which may be varied or changed as required, dependent upon site conditions, equipment limitations or limitations imposed by the procedure. In all instances, the ultimate procedures employed should be documented and associated with the final report.

Mention of trade names or commercial products does not constitute U.S. EPA endorsement or recommendation for use.

2.0 METHOD SUMMARY

Prior to sampling, the site should be characterized by identifying on-site as well as off-site sources of airborne asbestos. The array of sampling locations and the schedule for sample collection, is critical to the success of an investigation. Generally, sampling strategies to characterize a single point source are fairly straightforward, while multiple point sources and area sources increase the complexity of the sampling strategy. It is not within the scope of this SOP to provide a generic asbestos air sampling plan. Experience, objectives, and site characteristics will dictate the sampling strategy.

During a site investigation, sampling stations should be arranged to distinguish spatial trends in airborne asbestos concentrations. Sampling schedules should be fashioned to establish temporal trends. The sampling strategy typically requires that the concentration of asbestos at the source (worst case) or area of concern (downwind), crosswind, as well as background (upwind) contributions be quantified. See Table 1 (Appendix A) for U.S. EPA/ERT recommended sampling set up for ambient air. Indoor asbestos sampling requires a different type of strategy which is identified in Table 2 (Appendix A). It is important to establish background levels of contaminants in order to develop a reference point from which to evaluate the source data. Field blanks and lot blanks can be utilized to determine other sources.

Much information can be derived from each analytical method previously mentioned. Each analytical method has specific sampling requirements and produce results which may or may not be applicable to a specific sampling effort. The site sampling

objectives should be carefully identified so as to select the most appropriate analytical method. Additionally, some preparation (i.e., lot blanks results) prior to site sampling may be required, these requirements are specified in the analytical methods.

3.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

3.1 Sample Preservation

No preservation is required for asbestos samples.

3.2 Sample Handling, Container and Storage Procedures

1. Place a sample label on the cassette indicating a unique sampling number. Do not put sampling cassettes in shirt or coat pockets as the filter can pick up fibers. The original cassette box is used to hold the samples.
2. Wrap the cassette individually in a plastic sample bag. Each bag should be marked indicating sample identification number, total volume, and date.
3. The wrapped sampling cassettes should be placed upright in a rigid container so that the cassette cap is on top and cassette base is on bottom. Use enough packing material to prevent jostling or damage. Do not use vermiculite as packing material for samples. If possible, hand carry to lab.
4. Provide appropriate documentation with samples (i.e., chain of custody and requested analytical methodology).

4.0 INTERFERENCES AND POTENTIAL PROBLEMS

Flow rates exceeding 16 liters/minute (L/min) which could result in filter destruction due to (a) failure of its physical support under force from the increased pressure drop; (b) leakage of air around the filter mount so that the filter is bypassed, or (c) damage to the asbestos structures due to increased impact velocities.

4.1 U.S. EPA's Superfund Method

4.1.1 Direct-transfer TEM Specimen Preparation Methods

Direct-Transfer TEM specimen preparation methods have the following significant interferences:

- The achievable detection limit is restricted by the particulate density on the filter, which in turn is controlled by the sampled air volume and the total suspended particulate concentration in the atmosphere being sampled.
- The precision of the result is dependent on the uniformity of the deposit of asbestos structures on the sample collection filter.
- Air samples must be collected so that they have particulate and fiber loadings within narrow ranges. If too high a particulate loading occurs on the filter, it is not possible to prepare satisfactory TEM specimens by a direct-transfer method. If too high a fiber loading occurs on the filter, even if satisfactory TEM specimens can be prepared, accurate fiber counting will not be possible.

4.1.2 Indirect TEM Specimen Preparation Methods

Indirect TEM specimen preparation methods have the following interferences:

- The size distribution of asbestos structures is modified.
- There is increased opportunity for fiber loss or introduction of extraneous contamination.
- When sample collection filters are ashed, any fiber contamination in the filter medium is concentrated on the TEM specimen grid.

It can be argued that direct methods yield an under-estimate of the asbestos structure concentration because many of the asbestos fibers present are concealed by other particulate material with which they are associated. Conversely, indirect methods can be considered to yield an over-estimate because some types of complex asbestos structures disintegrate

during the preparation, resulting in an increase in the numbers of structures counted.

4.2 U.S. EPA's Modified Yamate Method for TEM

High concentrations of background dust interfere with fiber identification.

4.3 NIOSH Method for TEM

Other amphibole particles that have aspect ratios greater than 3:1 and elemental compositions similar to the asbestos minerals may interfere in the TEM analysis. Some non-amphibole minerals may give electron diffraction patterns similar to amphiboles. High concentrations of background dust interfere with fiber identification.

4.4 NIOSH Method for PCM

PCM cannot distinguish asbestos from non-asbestos fibers; therefore, all particles meeting the counting criteria are counted as total asbestos fibers. Fiber less than 0.25 μm in length will not be detected by this method. High levels of non-fibrous dust particles may obscure fibers in the field of view and increase the detection limit.

5.0 EQUIPMENT/MATERIALS

5.1 Sampling Pump

The constant flow or critical orifice controlled sampling pump should be capable of a flow-rate and pumping time sufficient to achieve the desired volume of air sampled.

The lower flow personal sampling pumps generally provide a flow rate of 20 cubic centimeters/minute (cc/min) to 4 L/min. These pumps are usually battery powered. High flow pumps are utilized when flow rates between 2 L/min to 20 L/min are required. High flow pumps are used for short sampling periods so as to obtain the desired sample volume. High flow pumps usually run on AC power and can be plugged into a nearby outlet. If an outlet is not available then a generator should be obtained. The generator should be positioned downwind from the sampling pump. Additional voltage may be required if more than one pump is plugged into the same generator. Several

electrical extension cords may be required if sampling locations are remote.

The recommended volume for the Superfund method (Phase I) requires approximately 20 hours to collect. Such pumps typically draw 6 amps at full power so that 2 lead/acid batteries should provide sufficient power to collect a full sample. The use of line voltage, where available, eliminates the difficulties associated with transporting stored electrical energy.

A stand should be used to hold the filter cassette at the desired height for sampling and the filter cassette shall be isolated from the vibrations of the pump.

5.2 Filter Cassette

The cassettes are purchased with the required filters in position, or can be assembled in a laminar flow hood or clean area. When the filters are in position, a shrink cellulose band or adhesive tape should be applied to cassette joints to prevent air leakage.

5.2.1 TEM Cassette Requirements

Commercially available field monitors, comprising 25 mm diameter three-piece cassettes, with conductive extension cowls shall be used for sample collection. The cassette must be new and not previously used. The cassette shall be loaded with an MCE filter of pore size 0.45 μm , and supplied from a lot number which has been qualified as low background for asbestos determination. The cowls should be constructed of electrically conducting material to minimize electrostatic effects. The filter shall be backed by a 5 μm pore size MCE filter (Figure 1, Appendix B).

5.2.2 PCM Cassette Requirements

NIOSH Method 7400, PCM involves using a 0.8 to 1.2 μm mixed cellulose ester membrane, 25 mm diameter, 50 mm conductive cowl on cassette (Figure 2, Appendix B). Some labs are able to perform PCM and TEM analysis on the same filter; however, this should be discussed with the laboratory prior to sampling.

5.3 Other Equipment

- Inert tubing with glass cyclone and hose barb
- Whirlbags (plastic bags) for cassettes

- Tools - small screw drivers
- Container - to keep samples upright
- Generator or electrical outlet (may not be required)
- Extension cords (may not be required)
- Multiple plug outlet
- Sample labels
- Air data sheets
- Chain of Custody records

6.0 REAGENTS

Reagents are not required for the preservation of asbestos samples.

7.0 PROCEDURES

7.1 Air Volumes and Flow Rates

Sampling volumes are determined on the basis of how many fibers need to be collected for reliable measurements. Therefore, one must estimate how many airborne fibers may be in the sampling location.

Since the concentration of airborne aerosol contaminants will have some effect on the sample, the following is a suggested criteria to assist in selecting a flow rate based on real-time aerosol monitor (RAM) readings in milligrams/cubic meter (mg/m^3).

	Concentration	Flow Rate
• Low RAM readings:	$<6.0 \text{ mg}/\text{m}^3$	11-15. L/min
• Medium RAM readings:	$>6.0 \text{ mg}/\text{m}^3$	7.5 L/min
• High RAM readings:	$>10. \text{ mg}/\text{m}^3$	2.5 L/min

In practice, pumps that are available for environmental sampling at remote locations operate under a maximum load of approximately 12 L/min.

7.1.1 U.S. EPA's Superfund Method

The Superfund Method incorporates an indirect preparation procedure to provide flexibility in the amount of deposit that can be tolerated on the sample filter and to allow for the selective concentration of asbestos prior to analysis. To minimize contributions to background contamination from asbestos present in the plastic matrices of membrane filters while allowing for sufficient quantities of asbestos to be collected, this method also requires the collection of a larger volume of air per unit area of filter than has traditionally been collected

for asbestos analysis. Due to the need to collect large volumes of air, higher sampling flow rates are recommended in this method than have generally been employed for asbestos sampling in the past. As an alternative, samples may be collected over longer time intervals. However, this restricts the flexibility required to allow samples to be collected while uniform meteorological conditions prevail.

The sampling rate and the period of sampling should be selected to yield as high a sampled volume as possible, which will minimize the influence of filter contamination. Wherever possible, a volume of 15 cubic meters (15,000 L) shall be sampled for those samples intended for analysis only by the indirect TEM preparation method (Phase 1 samples). For those samples to be prepared by both the indirect and the direct specimen preparation methods (Phase 2 samples), the volumes must be adjusted so as to provide a suitably-loaded filter for the direct TEM preparation method. One option is to collect filters at several loadings to bracket the estimated optimum loading for a particular site. Such filters can be screened in the laboratory so that only those filters closest to optimal loading are analyzed. It has been found that the volume cannot normally exceed 5 cubic meters (5000 L) in an urban or agricultural area, and 10 cubic meters (10,000 L) in a rural area for samples collected on a 25 mm filter and prepared by a direct-transfer technique.

An upper limit to the range of acceptable flow rates for this method is 15 L/min. At many locations, wind patterns exhibit strong diurnal variations. Therefore, intermittent sampling (sampling over a fixed time interval repeated over several days) may be necessary to accumulate 20 hours of sampling time over constant wind conditions. Other sampling objectives also may necessitate intermittent sampling. The objective is to design a sampling schedule so that samples are collected under uniform conditions throughout the sampling interval. This method provides for such options. Air volumes collected on Phase 1 samples are maximized (<16 L/min). Air volumes collected on Phase 2 samples are limited to provide optimum loading for filters to be prepared by a direct-transfer procedure.

7.1.2 U.S. EPA's Modified Yamate Method for TEM

U.S. EPA's TEM method requires a minimum volume

of 560 L and a maximum volume of 3,800 L in order to obtain an analytical sensitivity of 0.005 structures/cc. The optimal volume for TEM is 1200 L to 1800 L. These volumes are determined using a 200 mesh EM grid opening with a 25-mm filter cassette. Changes in volume would be necessary if a 37-mm filter cassette is used since the effective area of a 25 mm (385 sq mm) and 37 mm (855 sq mm) differ.

7.1.3 NIOSH Method for TEM and PCM

The minimum recommended volume for TEM and PCM is 400 L at 0.1 fiber/cc. Sampling time is adjusted to obtain optimum fiber loading on the filter. A sampling rate of 1 to 4 L/min for eight hours (700 to 2800 L) is appropriate in non-dusty atmospheres containing 0.1 fiber/cc. Dusty atmospheres i.e., areas with high levels of asbestos, require smaller sample volumes (<400 L) to obtain countable samples.

In such cases, take short, consecutive samples and average the results over the total collection time. For documenting episodic exposures, use high flow rates (7 to 16 L/min) over shorter sampling times. In relatively clean atmospheres where targeted fiber concentrations are much less than 0.1 fiber/cc, use larger sample volumes (3,000 to 10,000 L) to achieve quantifiable loadings. Take care, however, not to overload the filter with background dust. If > 50% of the filter surface is covered with particles, the filter may be too overloaded to count and will bias the measured fiber concentration. Do not exceed 0.5 mg total dust loading on the filter.

7.2 Calibration Procedures

In order to determine if a sampling pump is measuring the flow rate or volume of air correctly, it is necessary to calibrate the instrument. Sampling pumps should be calibrated immediately before and after each use. Preliminary calibration should be conducted using a primary calibrator such as a soap bubble type calibrator, (e.g., a Buck Calibrator, Gilibrator, or equivalent primary calibrator) with a representative filter cassette installed between the pump and the calibrator. The representative sampling cassette can be reused for calibrating other pumps that will be used for asbestos sampling. The same cassette lot used for sampling should also be used for the calibration. A sticker should be affixed to the outside of the extension cowl marked "Calibration Cassette."

A rotameter can be used provided it has been recently precalibrated with a primary calibrator. Three separate constant flow calibration readings should be obtained both before sampling and after sampling. Should the flow rate change by more than 5% during the sampling period, the average of the pre- and post-calibration rates will be used to calculate the total sample volume. The sampling pump used shall provide a non-fluctuating air-flow through the filter, and shall maintain the initial volume flow-rate to within $\pm 10\%$ throughout the sampling period. The mean value of these flow-rate measurements shall be used to calculate the total air volume sampled. A constant flow or critical orifice controlled pump meets these requirements. If at any time the measurement indicates that the flow-rate has decreased by more than 30%, the sampling shall be terminated. Flexible tubing is used to connect the filter cassette to the sampling pump. Sampling pumps can be calibrated prior to coming on-site so that time is saved when performing on-site calibration.

7.2.1 Calibrating a Personal Sampling Pump with an Electronic Calibrator

1. See Manufacturer's manual for operational instructions.
2. Set up the calibration train as shown in (Figure 3, Appendix B) using a sampling pump, electronic calibrator, and a representative filter cassette. The same lot sampling cassette used for sampling should also be used for calibrating.
3. To set up the calibration train, attach one end of the PVC tubing (approx. 2 foot) to the cassette base; attach the other end of the tubing to the inlet plug on the pump. Another piece of tubing is attached from the cassette cap to the electronic calibrator.
4. Turn the electronic calibrator and sampling pump on. Create a bubble at the bottom of the flow chamber by pressing the bubble initiate button. The bubble should rise to the top of the flow chamber. After the bubble runs its course, the flow rate is shown on the LED display.
5. Turn the flow adjust screw or knob on the pump until the desired flow rate is attained.

6. Perform the calibration three times until the desired flow rate of $\pm 5\%$ is attained.

7.2.2 Calibrating a Rotameter with an Electronic Calibrator

1. See manufacturer's manual for operational instructions.
2. Set up the calibration train as shown in (Figure 4, Appendix B) using a sampling pump, rotameter, and electronic calibrator.
3. Assemble the base of the flow meter with the screw provided and tighten in place. The flow meter should be mounted within 6° vertical.
4. Turn the electronic calibrator and sampling pump on.
5. Create a bubble at the bottom of the flow chamber by pressing the bubble initiate button. The bubble should rise to the top of the flow chamber. After the bubble runs its course, the flow rate is shown on the LED display.
6. Turn the flow adjust screw or knob on the pump until the desired flow rate is attained.
7. Record the electronic calibrator flow rate reading and the corresponding rotameter reading. Indicate these values on the rotameter (sticker). The rotameter should be able to work within the desired flow range. Readings can also be calibrated for 10 cm³ increments for Low Flow rotameters, 500 cm³ increments for medium flow rotameters and 1 liter increments for high flow rotameters.
8. Perform the calibration three times until the desired flow rate of $\pm 5\%$ is attained. Once on site, a secondary calibrator, i.e., rotameter may be used to calibrate sampling pumps.

7.2.3 Calibrating a Personal Sampling Pump with a Rotameter

1. See manufacturer's manual for Rotameter's Operational Instructions.

2. Set up the calibration train as shown in (Figure 5, Appendix B) using a rotameter, sampling pump, and a representative sampling cassette.
3. To set up the calibration train, attach one end of the PVC tubing (approx. 2 ft) to the cassette base; attach the other end of the tubing to the inlet plug on the pump. Another piece of tubing is attached from the cassette cap to the rotameter.
4. Assemble the base of the flow meter with the screw provided and tighten in place. The flow meter should be mounted within 6° vertical.
5. Turn the sampling pump on.
6. Turn the flow adjust screw (or knob) on the personal sampling pump until the float ball on the rotameter is lined up with the precalibrated flow rate value. A sticker on the rotameter should indicate this value.
7. A verification of calibration is generally performed on-site in the clean zone immediately prior to the sampling.

7.3. Meteorology

It is recommended that a meteorological station be established. If possible, sample after two to three days of dry weather and when the wind conditions are at 10 mph or greater. Record wind speed, wind direction, temperature, and pressure in a field logbook. Wind direction is particularly important when monitoring for asbestos downwind from a fixed source.

7.4 Ambient Sampling Procedures

7.4.1 Pre-site Sampling Preparation

1. Determine the extent of the sampling effort, the sampling methods to be employed, and the types and amounts of equipment and supplies needed.
2. Obtain necessary sampling equipment and ensure it is in working order and fully charged (if necessary).

3. Perform a general site survey prior to site entry in accordance with the site specific Health and Safety plan.
4. Once on-site the calibration is performed in the clean zone. The calibration procedures are listed in Section 7.2.
5. After calibrating the sampling pump, mobilize to the sampling location.

7.4.2 Site Sampling

1. To set up the sampling train, attach the air intake hose to the cassette base. Remove the cassette cap (Figure 6 and 7, Appendix B). The cassette should be positioned downward, perpendicular to the wind
2. If AC or DC electricity is required then turn it on. If used, the generator should be placed 10 ft. downwind from the sampling pump.
3. Record the following in a field logbook: date, time, location, sample identification number, pump number, flow rate, and cumulative time.
4. Turn the pump on. Should intermittent sampling be required, sampling filters must be covered between active periods of sampling. To cover the sample filter: turn the cassette to face upward, place the cassette cap on the cassette, remove the inlet plug from the cassette cap, attach a rotameter to the inlet opening of the cassette cap to measure the flow rate, turn off the sampling pump, place the inlet plug into the inlet opening on the cassette cap. To resume sampling: remove the inlet plug, turn on the sampling pump, attach a rotameter to measure the flow rate, remove the cassette cap, replace the inlet plug in the cassette cap and invert the cassette, face downward and perpendicular to the wind.
5. Check the pump at sampling midpoint if sampling is longer than 4 hours. The generators may need to be regassed depending on tank size. If a filter darkens in appearance or if loose dust is seen in the filter, a second sample should be started.

6. At the end of the sampling period, orient the cassette up, turn the pump off.
7. Check the flow rate as shown in Section 7.2.3. When sampling open-faced, the sampling cap should be replaced before post calibrating. Use the same cassette used for sampling for post calibration (increase dust/fiber loading may have altered the flow rate).
8. Record the post flow rate.
9. Record the cumulative time or run.
10. Remove the tubing from the sampling cassette. Still holding the cassette upright, replace the inlet plug on the cassette cap and the outlet plug on the cassette base.

7.4.3. Post Site Sampling

1. Follow handling procedures in Section 3.2, steps 1-4.
2. Obtain an electronic or hard copy of meteorological data which occurred during the sampling event. Record weather: wind speed, ambient temperature, wind direction, and precipitation. Obtaining weather data several days prior to the sampling event can also be useful.

7.5 Indoor Sampling Procedures

PCM analysis is used for indoor air samples. When analysis shows total fiber count above the OSHA action level 0.1 f/cc then TEM (U.S. EPA's Modified Yamate Method) is used to identify asbestos from non-asbestos fibers.

Sampling pumps should be placed four to five feet above ground level away from obstructions that may influence air flow. The pump can be placed on a table or counter. Refer to Table 2 (Appendix A) for a summary of indoor sampling locations and rationale for selection.

Indoor sampling utilizes high flow rates to increased sample volumes (2000 L for PCM and 2800 to 4200 L for TEM) in order to obtain lower detection limits below the standard, (i.e., 0.01 f/cc or lower [PCM]

and 0.005 structures/cc or lower [TEM]).

7.5.1 Aggressive Sampling Procedures

Sampling equipment at fixed locations may fail to detect the presence of asbestos fibers. Due to limited air movement, many fibers may settle out of the air onto the floor and other surfaces and may not be captured on the filter. In the past, an 8-hour sampling period was recommended to cover various air circulation conditions. A quicker and more effective way to capture asbestos fibers is to circulate the air artificially so that the fibers remain airborne during sampling. The results from this sampling option typifies worst case condition. This is referred to as aggressive air sampling for asbestos. Refer to Table 2 for sample station locations.

1. Before starting the sampling pumps, direct forced air (such as a 1-horsepower leaf blower or large fan) against walls, ceilings, floors, ledges, and other surfaces in the room to initially dislodge fibers from surfaces. This should take at least 5 minutes per 1000 sq. ft. of floor.
2. Place a 20-inch fan in the center of the room. (Use one fan per 10,000 cubic feet of room space.) Place the fan on slow speed and point it toward the ceiling.
3. Follow procedures in Section 7.4.1 and 7.4.2 (Turn off the pump and then the fan(s) when sampling is complete.).
4. Follow handling procedures in Section 3.2, steps 1-4.

8.0 CALCULATIONS

The sample volume is calculated from the average flow rate of the pump multiplied by the number of minutes the pump was running (volume = flow rate X time in minutes). The sample volume should be submitted to the laboratory and identified on the chain of custody for each sample (zero for lot, field and trip blanks).

The concentration result is calculated using the sample volume and the numbers of asbestos structures reported after the application of the cluster and matrix counting criteria.

9.0 QUALITY ASSURANCE/ QUALITY CONTROL

Follow all QA/QC requirements from the laboratories as well as the analytical methods.

9.1 TEM Requirements

1. Examine lot blanks to determine the background asbestos structure concentration.
2. Examine field blanks to determine whether there is contamination by extraneous asbestos structures during specimen preparation.
3. Examine of laboratory blanks to determine if contamination is being introduced during critical phases of the laboratory program.
4. To determine if the laboratory can satisfactorily analyze samples of known asbestos structure concentrations, reference filters shall be examined. Reference filters should be maintained as part of the laboratory's Quality Assurance program.
5. To minimize subjective effects, some specimens should be recounted by a different microscopist.
6. Asbestos laboratories shall be accredited by the National Voluntary Laboratory Accreditation Program.
7. At this time, performance evaluation samples for asbestos in air are not available for Removal Program Activities.

9.2 PCM Requirements

1. Examine reference slides of known concentration to determine the analyst's ability to satisfactorily count fibers. Reference slides should be maintained as part of the laboratory's quality assurance program.
2. Examine field blanks to determine if there is contamination by extraneous structures during sample handling.

3. Some samples should be relabeled then submitted for counting by the same analyst to determine possible bias by the analyst.
4. Participation in a proficiency testing program such as the AIHA-NIOSH proficiency analytical testing (PAT) program.

10.0 DATA VALIDATION

Results of quality control samples will be evaluated for contamination. This information will be utilized to qualify the environmental sample results accordingly with the project's data quality objectives.

11.0 HEALTH AND SAFETY

When working with potentially hazardous materials, follow U.S. EPA, OSHA, and corporate health and safety procedures. More specifically, when entering an unknown situation involving asbestos, a powered air purifying respirator (PAPR) (full face-piece) is necessary in conjunction with HEPA filter cartridges. See applicable regulations for action level, PEL, TLV, etc. If previous sampling indicates asbestos concentrations are below personal health and safety levels, then Level D personal protection is adequate.

12.0 REFERENCES

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1987.

APPENDIX A

Tables

TABLE 1. SAMPLE STATIONS FOR OUTDOOR SAMPLING		
Sample Station Location	Sample Numbers	Rationale
Upwind/Background ⁽¹⁾	Collect a minimum of two simultaneous upwind/background samples 30° apart from the prevailing windlines.	Establishes background fiber levels.
Downwind	Deploy a minimum of 3 sampling stations in a 180 degree arc downwind from the source.	Indicates if asbestos is leaving the site.
Site Representative and/or Worst Case	Obtain one site representative sample which shows average condition on-site or obtain worst case sample (optional).	Verify and continually confirm and document selection of proper levels of worker protection.

⁽¹⁾ More than one background station may be required if the asbestos originates from different sources.

APPENDIX A (Cont'd)

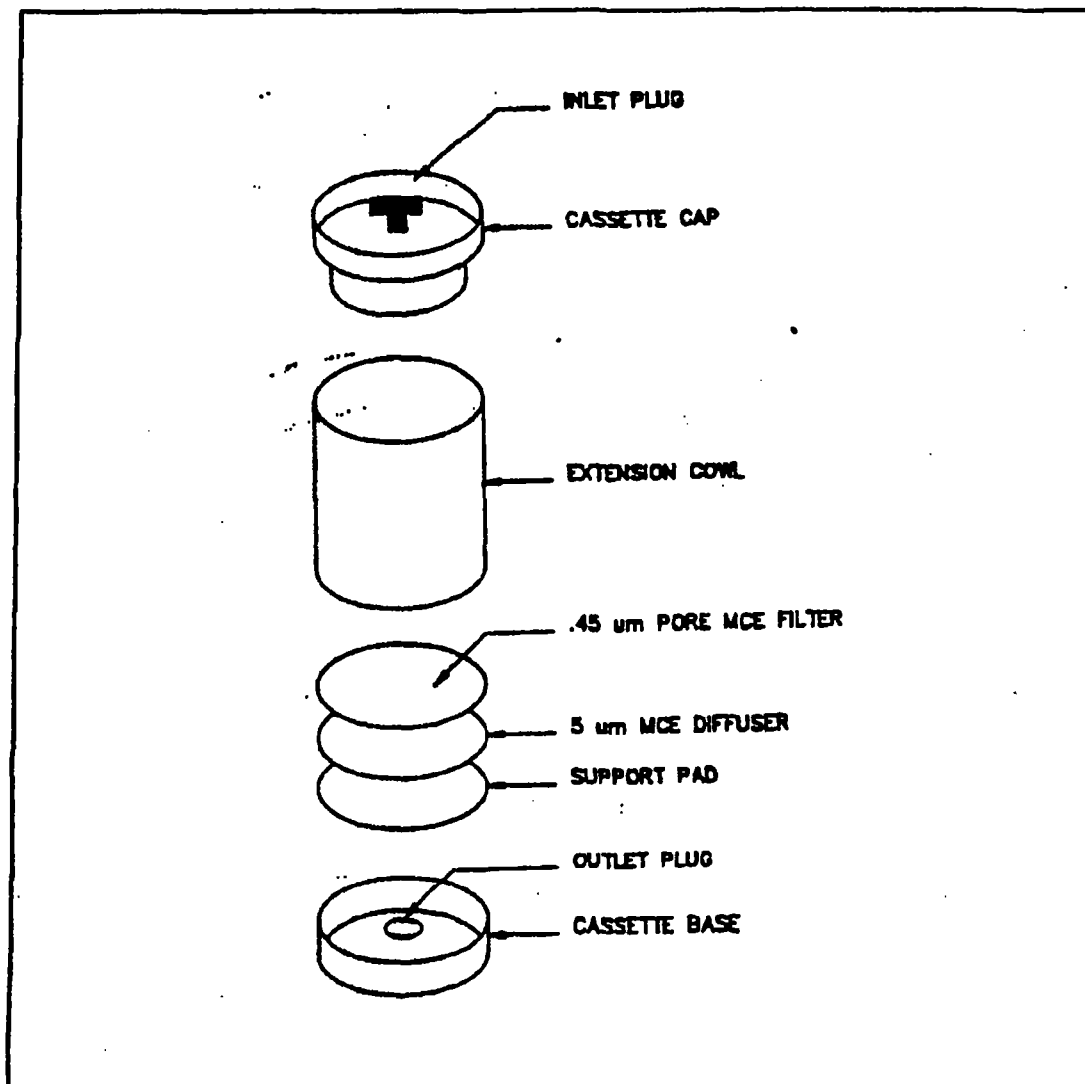
Tables

TABLE 2 SAMPLE STATIONS FOR INDOOR SAMPLING		
Sample Station Location	Sample Numbers	Rationale
Indoor Sampling	<p>If a work site is a single room, disperse 5 samplers throughout the room.</p> <p>If the work site contains up to 5 rooms, place at least one sampler in each room.</p> <p>If the work site contains more than 5 rooms, select a representative sample of the rooms.</p>	Establishes representative samples from a homogeneous area.
Upwind/Background	If outside sources are suspected, deploy a minimum of two simultaneous upwind/background samples 30° apart from the prevailing windlines.	Establish whether indoor asbestos concentrations are coming from an outside source.
Worst Case	Obtain one worst case sample, i.e., aggressive sampling (optional).	Verify and continually confirm and document selection of proper levels of worker protection.

APPENDIX B

Figures

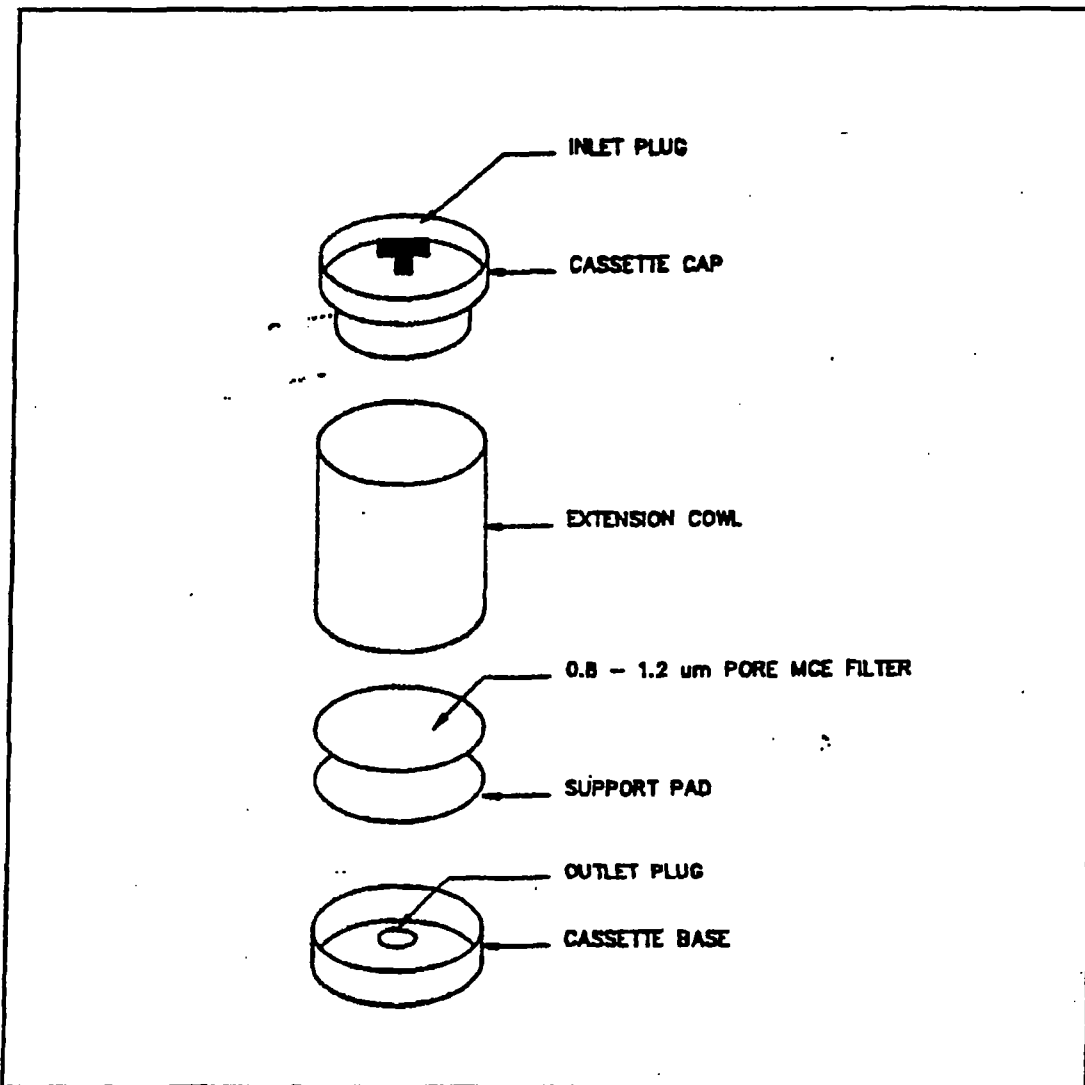
FIGURE 1. Transmission Electron Microscopy Filter Cassette



APPENDIX B (Cont'd)

Figures

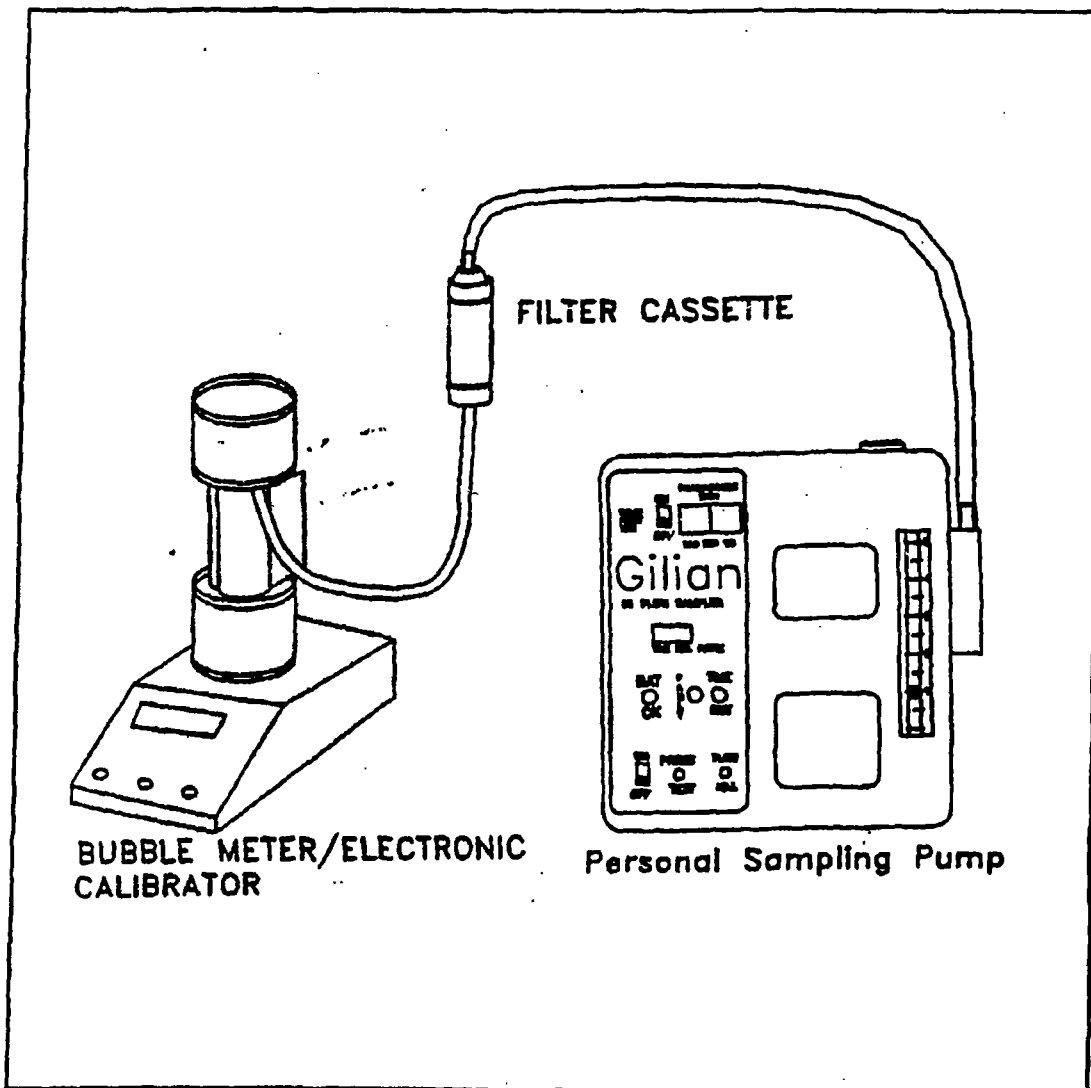
FIGURE 2. Phase Contrast Microscopy Filter Cassette



APPENDIX B (Cont'd)

Figures

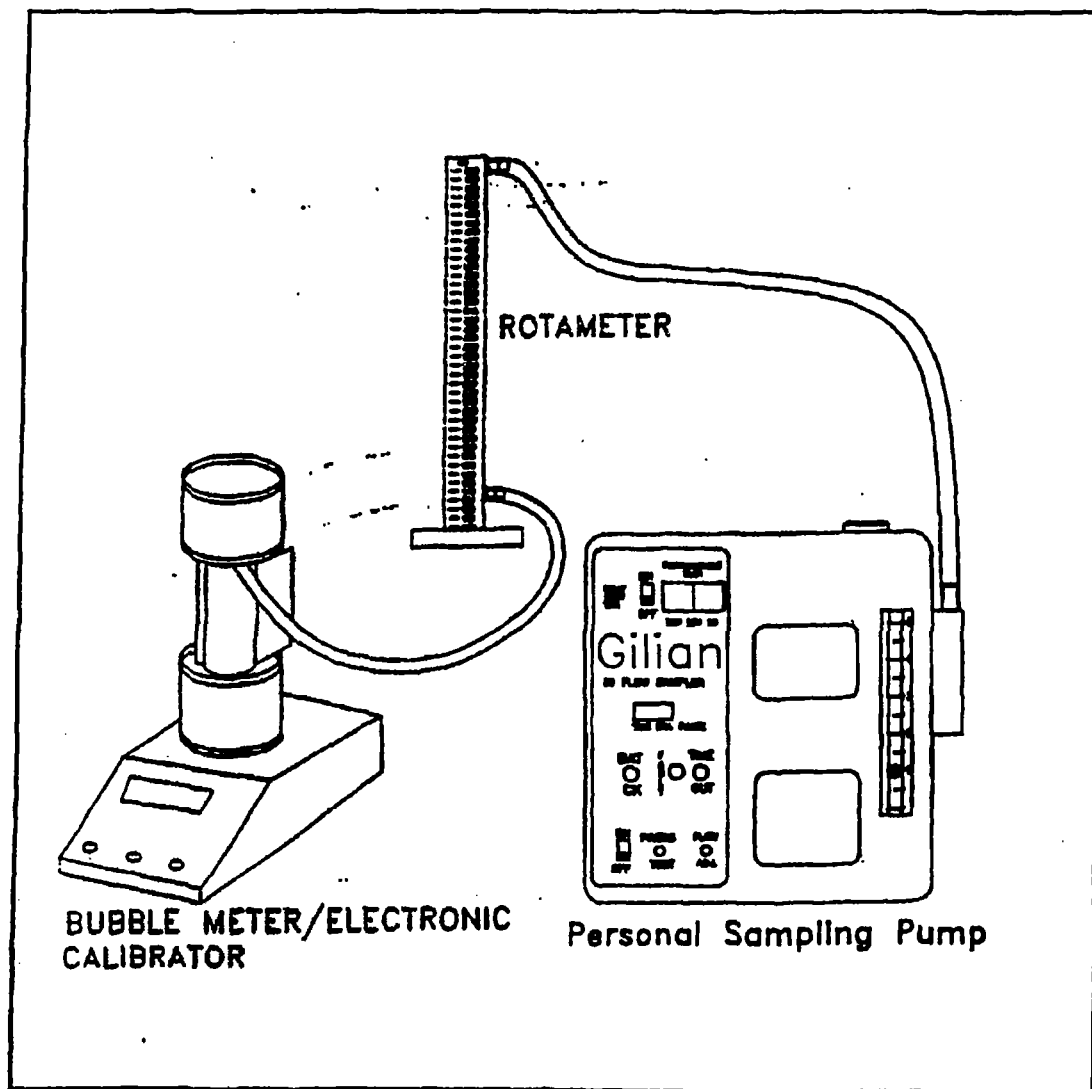
FIGURE 3. Calibrating a Personal Sampling Pump with a Bubble Meter



APPENDIX B (Cont'd)

Figures

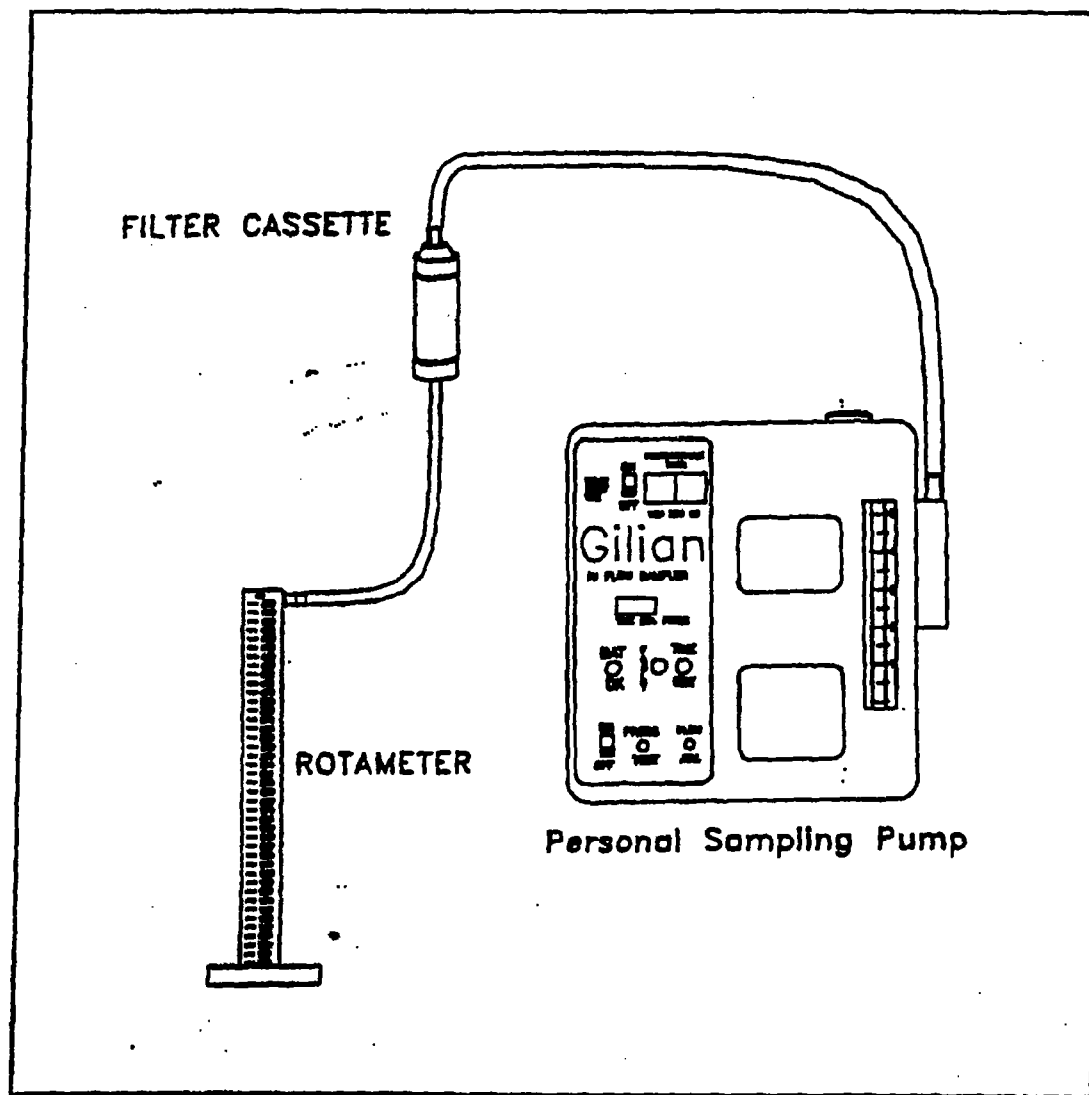
FIGURE 4. Calibrating a Rotameter with a Bubble Meter



APPENDIX B (Cont'd)

Figures

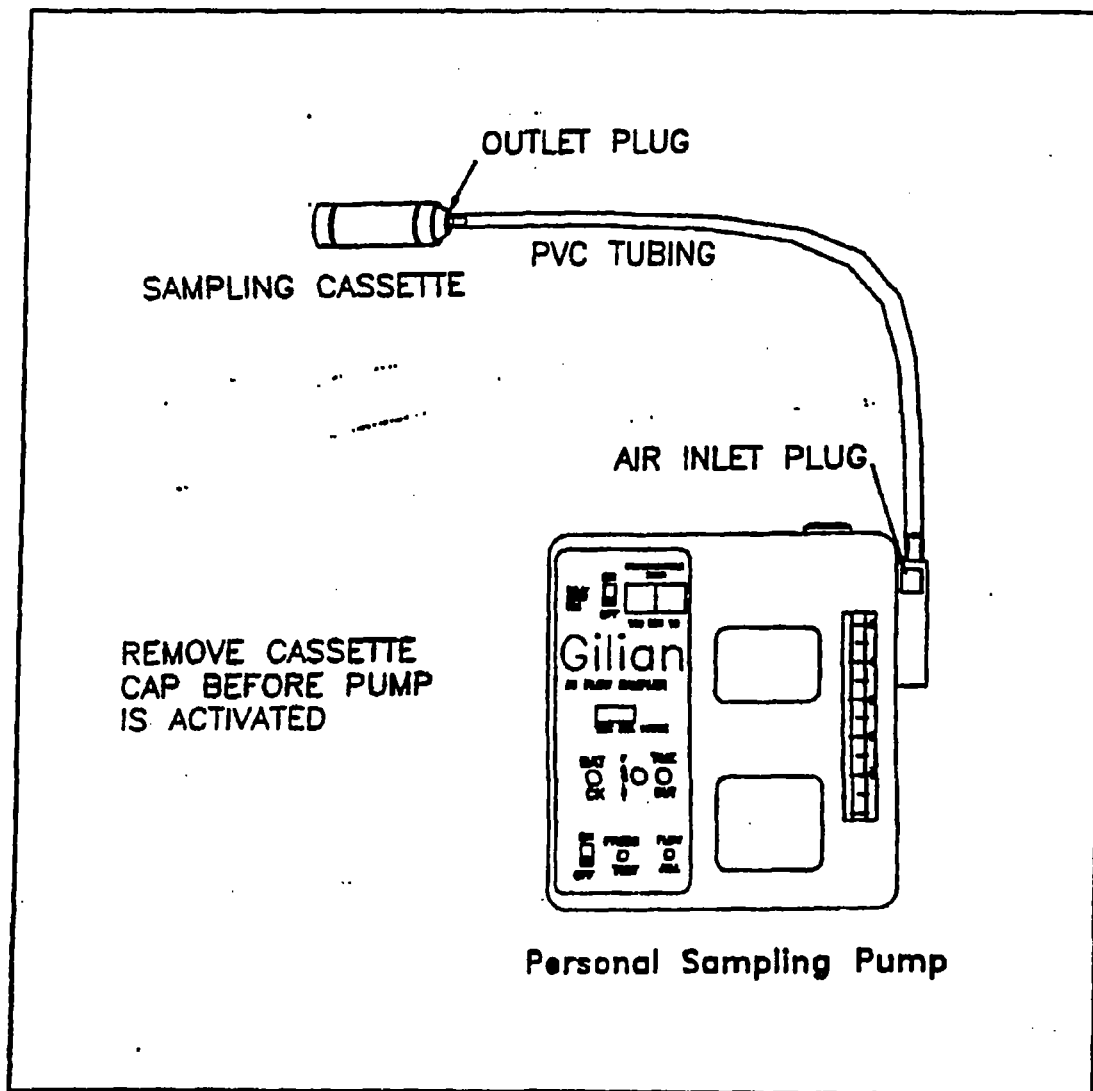
FIGURE 5. Calibrating a Sampling Pump with a Rotameter



APPENDIX B (Cont'd)

Figures

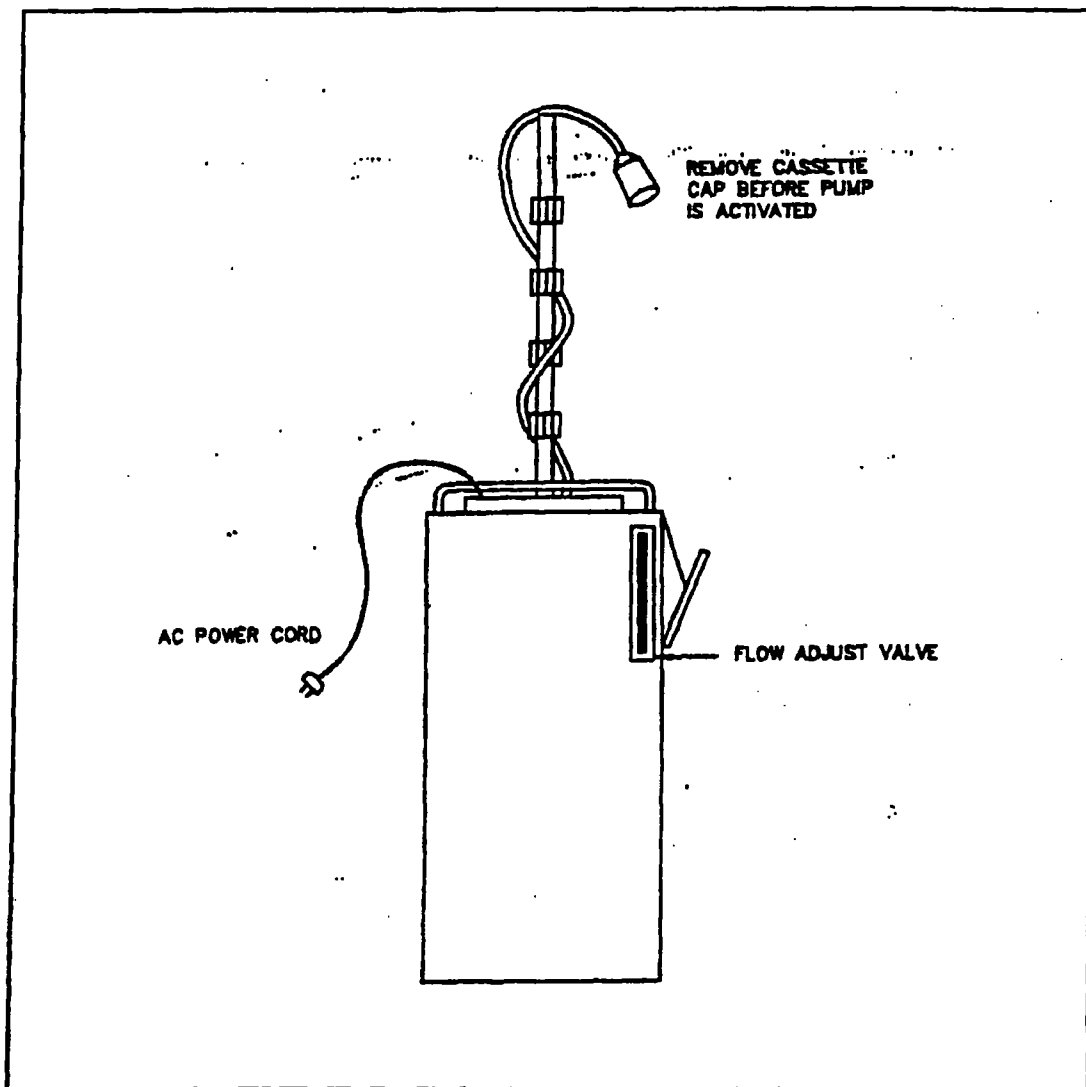
FIGURE 6. Personal Sampling Train for Asbestos



APPENDIX B (Cont'd)

Figures

FIGURE 7. High Flow Sampling Train for Asbestos



APPENDIX C

**LIBBY AMPHIBOLE (TREMOLITE/ACTINOLITE
SERIES) PLM METHOD 9002, ISSUE 2**

ASBESTOS (bulk) by PLM

9002

various

MW: various

CAS: 1332-21-4

RTECS: C16475000

METHOD: 9002, Issue 2

EVALUATION: PARTIAL

Issue 1: 15 May 1989

Issue 2: 15 August 1994

EPA Standard (Bulk): 1%

PROPERTIES: solid, fibrous, crystalline, anisotropic

SYNONYMS [CAS #]: actinolite [77536-66-4], or ferroactinolite [15669-07-5]; amosite [12172-73-5]; anthophyllite [77536-67-6]; chrysotile [12001-29-5]; serpentine [18786-24-8]; crocidolite [12001-28-4]; tremolite [77536-68-6]; amphibole asbestos [1332-21-4].

SAMPLING		MEASUREMENT	
BULK SAMPLE:	1 to 10 grams	TECHNIQUE:	MICROSCOPY, STEREO AND POLARIZED LIGHT, WITH DISPERSION STAINING
SHIPMENT:	seal securely to prevent escape of asbestos	ANALYTE:	actinolite asbestos, amosite, anthophyllite asbestos, chrysotile, crocidolite, tremolite asbestos
SAMPLE STABILITY:	stable	EQUIPMENT:	microscope, polarized light; 100-400X dispersion staining objective, stereo microscope: 10-45X
BLANKS:	none required	RANGE:	1% to 100% asbestos
ACCURACY		ESTIMATED LOD:	<1% asbestos [1]
		PRECISION:	not determined
RANGE STUDIED:	<1% to 100% asbestos		
BIAS:	not determined		
PRECISION:	not determined		
ACCURACY:	not determined		

APPLICABILITY: this method is useful for the qualitative identification of asbestos and the semi-quantitative determination of asbestos content of bulk samples. The method measures percent asbestos as perceived by the analyst in comparison to standard area projections, photos, and drawings, or trained experience. The method is not applicable to samples containing large amounts of fine fibers below the resolution of the light microscope.

INTERFERENCES: Other fibers with optical properties similar to the asbestos minerals may give positive interferences. Optical properties of asbestos may be obscured by coating on the fibers. Fibers finer than the resolving power of the microscope (ca. 0.3 μ m) will not be detected. Heat and acid treatment may alter the index of refraction of asbestos and change its color.

OTHER METHODS: This method (originally designated as method 7403) is designed for use with NIOSH Methods 7400 (phase contrast microscopy) and 7402 (electron microscopy/EDS). The method is similar to the EPA bulk asbestos method [1].

REAGENTS:

1. Refractive index (RI) liquids for Dispersion Staining: high-dispersion (HD) series, 1.550, 1.605, 1.620.
2. Refractive index liquids: 1.670, 1.680, and 1.700.
3. Asbestos reference samples such as SRM #1866, available from the National Institute of Standards and Technology.*
4. Distilled Water (optional).
5. Concentrated HCl: ACS reagent grade.

* See SPECIAL PRECAUTIONS.

EQUIPMENT:

1. Sample containers: screw-top plastic vials of 10- to 50-mL capacity.
2. Microscope, polarized light, with polarizer, analyzer, port for retardation plate, 360° graduated rotating stage, substage condenser with Irls, lamp, lamp Irls, and:
 - a. Objective lenses: 10X, 20X, and 40X or near equivalent.
 - b. Ocular lense: 10X minimum.
 - c. Eyeiece reticle: crosshair.
 - d. Dispersion staining objective lens or equivalent.
 - e. Compensator plate: ca. 550 nm ± 20 nm, retardation: "first order red" compensator.
3. Microscope slides: 75 mm x 25 mm.
4. Cover silps.
5. Ventilated hood or negative-pressure glove box.
6. Mortar and pestle: agate or porcelain.
7. Stereomicroscope, ca. 10 to 45X.
8. Light source: Incandescent or fluorescent.
9. Tweezers, dissecting needles, spatulas, probes, and scalpels.
10. Glassine paper or clean glass plate.
11. Low-speed hand drill with coarse burr bit (optional).

SPECIAL PRECAUTIONS: Asbestos, a human carcinogen, should be handled only in an exhaust hood (equipped with a HEPA filter) [2]. Precautions should be taken when collecting unknown samples, which may be asbestos, to preclude exposure to the person collecting the sample and minimize the disruption to the parent material [3]. Disposal of asbestos-containing materials should follow EPA Guidelines [4].

SAMPLING:

1. Place 1 to 10 g of the material to be analyzed in a sample container.
NOTE: For large samples (i.e., whole ceiling tiles) that are fairly homogenous, a representative small portion should be submitted for analysis. Sample size should be adjusted to ensure that it is representative of the parent material.
2. Make sure that sample containers are taped so they will not open in transit.
3. Ship the samples in a rigid container with sufficient packing material to prevent damage or sample loss.

SAMPLE PREPARATION:

4. Visually examine samples in the container and with a low-magnification stereomicroscope in a hood. (If necessary, a sample may be carefully removed from the container and placed on glassine transfer paper or clean glass plate for examination). Break off a portion of the sample and examine the edges for emergent fibers. Note the homogeneity of the sample. Some hard tiles can be broken, and the edges examined for emergent fibers. If fibers are found, make an estimate of the amount and type of fibers present, confirm fiber type (step 14) and quantify (step 15).

5. In a hood, open sample container and with tweezers remove small, representative portions of the sample.
 - a. If there are obvious separable layers, sample and analyze each layer separately.
 - b. If the sample appears to be slightly inhomogeneous, mix it in the sample container with tweezers or a spatula before taking the portion of analysis. Alternatively, take small representative portions of each type of material and place on a glass slide.
 - c. On hard tiles that may have thin, inseparable layers, use a scalpel to cut through all the layers for a representative sample. Then cut it into smaller pieces after placing RI liquid on it before trying to reduce the thickness. Alternatively, use a low-speed hand drill equipped with a burr bit to remove material from hard tiles. Avoid excessive heating of the sample which may alter the optical properties of the material.

NOTE: This type of sample often requires ashing or other specialized preparation, and may require transmission electron microscopy for detection of the short asbestos fibers which are characteristic of floor tiles.

- d. If the sample has large, hard particles, grind it in a mortar. Do not grind so fine that fiber characteristics are destroyed.
- e. If necessary, treat a portion of the sample in a hood with an appropriate solvent to remove binders, tars, and other interfering materials which may be present in the sample. Make corrections for the non-asbestos material removed by this process.

NOTE: Other methods of sample preparation such as acid washing and sodium metaphosphate treatment and ashing may be necessary, especially to detect low concentrations of asbestos. If needed, use as described in Reference [1].

6. After placing a few drops of RI liquid on the slide, put a small portion of sample in the liquid. Tease apart with a needle or smash small clumps with the flat end of a spatula or probe, producing a uniform thickness or particles so that better estimates of projected area percentages can be made. Mix the fibers and particles on the slide so that they are as homogeneous as possible.

NOTE: An even dispersion of sample should cover the entire area under the cover slip. Some practice will be necessary to judge the right amount of material to place on the slide. Too little sample may not give sufficient information and too much sample cannot be easily analyzed.

CALIBRATION AND QUALITY CONTROL:

7. Check for contamination each day of operation. Wipe microscope slides and cover slips with lens paper before using. Check refractive index liquids. Record results in a separate logbook.
8. Verify the refractive indices of the refractive index liquids used once per week of operation. Record these checks in a separate logbook.
9. Follow the manufacturer's instructions for illumination, condenser alignment and other microscope adjustments. Perform these adjustments prior to each sample set.
10. Determine percent of each identified asbestos species by comparison to standard projections (Figure 1) [1]. If no fibers are detected in a homogeneous sample, examine at least two additional preparations before concluding that no asbestos is present.
11. If it appears that the preparation technique might not be able to produce a homogeneous or representative sample on the slide, prepare a duplicate slide and average the results. Occasionally, when the duplicate results vary greatly, it will be necessary to prepare additional replicate slides and average all the replicate results. Prepare duplicate slides of at least 10% of the samples analyzed. Average the results for reporting.
12. Analyze about 5% blind samples of known asbestos content.
13. Laboratories performing this analytical method should participate in the National Voluntary Laboratory Accreditation Program [5] or a similar interlaboratory quality control program. Each analyst should have complete formal training in polarized light microscopy and its application to crystalline materials. In lieu of formal training, laboratory training in asbestos bulk analysis under the direction of a trained asbestos bulk analyst may be substituted. Owing to the subjective nature of the method, frequent practice is essential in order to remain proficient in estimating projected area percentages.

QUALITATIVE ASSESSMENT:

14. Scan the slide to identify any asbestos minerals using the optical properties of morphology, refractive indices, color, pleochroism, birefringence, extinction characteristics, sign of elongation, and dispersion staining characteristics.

NOTE: Identification of asbestos using polarized light microscopy is unlike most other analytical methods. The quality of the results is dependent on the skill and judgment of the analyst. This method does not lend itself easily to a step-wise approach. Various procedures devised by different analysts may yield equivalent results. The following step-wise procedure repeatedly utilizes the sample preparation procedure previously outlined.

- a. Prepare a slide using 1.550 HD RI liquid. Adjust the polarizing filter such that the polars are partially crossed, with ca. 15° offset. Scan the preparation, examining the morphology for the presence of fibers. If no fibers are found, scan the additional preparations. If no fibers are found in any of the preparations, report that the sample does not contain asbestos, and stop the analysis at this point.
 - b. If fibers are found, adjust the polarizing filter such that the polars are fully crossed. If all of the fibers are isotropic (disappear at all angles of rotation) then those fibers are not asbestos. Fibrous glass and mineral wool, which are common components of suspect samples, are isotropic. If only isotropic fibers are found in the additional preparations, report no asbestos fibers detected, and stop the analysis.
 - c. If anisotropic fibers are found, rotate the stage to determine the angle of extinction. Except for tremolite-actinolite asbestos which has oblique extinction at 10-20°, the other forms of asbestos exhibit parallel extinction (Table 1). Tremolite may show both parallel and oblique extinction.
 - d. Insert the first order red compensator plate in the microscope and determine the sign of elongation. All forms of asbestos have a positive sign of elongation except for crocidolite. If the sign of elongation observed is negative, go to step "g."
- NOTE: To determine the direction of the sign of elongation on a particular microscope configuration, examine a known chrysotile sample and note the direction (NE-SW or NW-SE) of the blue coloration. Chrysotile has a positive sign of elongation.
- e. Remove the first-order red compensator and uncross the polarizer. Examine under plane polarized light for blue and gold-brown Becke colors at the fiber-oil interface (i.e., index of refraction match). Becke colors are not always evident. Examine fiber morphology for twisted, wavy bundles of fibers which are characteristic of chrysotile. Twisted, ribbon-like morphology with cellular internal features may indicate cellulose fibers. It may be necessary to cross the polars partially in order to see the fibers if the index of refraction is an exact match at 1.550. If the fibers appear to have higher index of refraction, go to step "h," otherwise continue.
 - f. Identification of chrysotile. Insert the dispersion staining objective. Observation of dispersion staining colors of blue and blue-magenta confirms chrysotile. Cellulose, which is a common interfering fiber at the 1.550 index of refraction, will not exhibit these dispersion staining colors. If chrysotile is found, go to step 15 for quantitative estimation.
 - g. Identification of crocidolite. Prepare a slide in 1.700 RI liquid. Examine under plane-polarized light (uncrossed polars); check for morphology of crocidolite. Fibers will be straight, with rigid appearance, and may appear blue or purple-blue. Crocidolite is pleochroic, i.e., it will appear to change its color (blue or gray) as it is rotated through plane polarized light. Insert the dispersion staining objective. The central stop dispersion staining color are red magenta and blue magenta, however, these colors are sometimes difficult to impossible to see because of the opacity of the dark blue fibers. If observations above indicate crocidolite, go to step 15 for quantitative estimation.
 - h. Identification of amosite. Prepare a slide in 1.680 RI liquid. Observe the fiber morphology for amosite characteristics: straight fibers and fiber bundles with broom-like or splayed ends. If the morphology matches amosite, examine the fibers using the dispersion staining objective. Blue and pale blue colors indicate the cummingtonite form of amosite, and gold and blue colors indicate the grunerite form of amosite. If amosite is confirmed by this test,

go to step 15 for quantitative estimation, otherwise continue.

- I. Identification of anthophyllite-tremolite-actinolite. Prepare a slide in 1.605 HD RI liquid. Examine morphology for comparison to anthophyllite-tremolite-actinolite asbestos. The refractive indices for these forms of asbestos vary naturally within the species. Anthophyllite can be distinguished from actinolite and tremolite by its nearly parallel extinction. Actinolite has a light to dark green color under plane-polarized light and exhibits some pieochroism. For all three, fibers will be straight, single fibers possibly with some larger composite fibers. Cleavage fragments may also be present. Examine using the central stop dispersion staining objective. Anthophyllite will exhibit central stop colors of blue and gold/gold-magenta; tremolite will exhibit pale blue and yellow; and actinolite will exhibit magenta and golden-yellow colors.

NOTE: In this refractive index range, wollastonite is a common interfering mineral with similar morphology including the presence of cleavage fragments. It has both positive and negative sign of elongation, parallel extinction, and central stop dispersion staining colors of pale yellow and pale yellow to magenta. If further confirmation of wollastonite versus anthophyllite is needed, go to step "J". If any of the above forms of asbestos were confirmed above, go to step 15 for quantitative estimation. If none of the tests above confirmed asbestos fibers, examine the additional preparations and if the same result occurs, report the absence of asbestos in this sample.

- J. Wash a small portion of the sample in a drop of concentrated hydrochloric acid on a slide. Place the slide, with cover slip in place, on a warm hot plate until dry. By capillary action, place 1.620 RI liquid under the cover slip and examine the slide. Wollastonite fibers will have a "cross-hatched" appearance across the length of the fibers and will not show central stop dispersion colors. Anthophyllite and tremolite will still show their original dispersion colors.

NOTE: There are alternative analysis procedures to the step-wise approach outlined above which will yield equivalent results. Some of these alternatives are:

- I. Perform the initial scan for the presence of asbestos using crossed polars as well as the first-order red compensator. This allows for simultaneous viewing of birefringent and amorphous materials as well as determine their sign of elongation. Some fibers which are covered with mortar may best be observed using this configuration.
- II. Some analysts prefer to mount their first preparation in a RI liquid different than any asbestos materials and conduct their initial examination under plane-polarized light.
- III. If alternative RI liquids are used from those specified, dispersion staining colors observed will also change. Refer to an appropriate reference for the specific colors associated with asbestos in the RI liquids actually used.

QUANTITATIVE ASSESSMENT:

15. Estimate the content of the asbestos type present in the sample using the 1.550 RI preparation. Express the estimate as an area percent of all material present, taking into account the loading and distribution of all sample material on the slide. Use Figure 1 as an aid in arriving at your estimate. If additional unidentified fibers are present in the sample, continue with the qualitative measurement (step 14).

NOTE: Point-counting techniques to determine percentages of the asbestos minerals are not generally recommended. The point-counting method only produces accurate quantitative data when the material on the slide is homogeneous and has a uniform thickness, which is difficult to obtain [6]. The point-counting technique is recommended by the EPA to determine the amount of asbestos in bulk [1]; however, in the more recent Asbestos Hazard Emergency Response Act (AHERA) regulations, asbestos quantification may be performed by a point-counting or equivalent estimation method [7].

16. Make a quantitative estimate of the asbestos content of the sample from the appropriate combination of the estimates from both the gross and microscopic examinations. If asbestos fibers are identified, report the material as "asbestos-containing". Asbestos content should be reported as a range of percent content. The range reported should be indicative of the analyst's precision in estimating asbestos content. For greater quantities use Figure 1 in arriving at your estimate.

EVALUATION OF METHOD:

The method is compiled from standard techniques used in mineralogy [8-13], and from standard laboratory procedures for bulk asbestos analysis which have been utilized for several years. These techniques have been successfully applied to the analysis of EPA Bulk Sample Analysis Quality Assurance Program samples since 1982 [1,5]. However, no formal evaluation of this method, as written, has been performed.

REFERENCES:

- [1] Perkins, R.L. and B.W. Harvey, U.S. Environmental Protection Agency. Test Method for the Determination of Asbestos in Bulk Building Materials. EPA/600/R-93/116 (June, 1993).
- [2] Criteria for a Recommended Standard...Occupational Exposure to Asbestos (Revised), U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-169 (1976), AS AMENDED IN NIOSH Statement at OSHA Public Hearing, (June 21, 1984).
- [3] Jankovic, J.T. Asbestos Bulk Sampling Procedure, Amer. Ind. Hyg. Assoc. J., B-8 to B-10, (February, 1985).
- [4] U.S. Environmental Protection Agency, "Asbestos Waste Management Guidance" EPA/530-SW-85-007, (May, 1985).
- [5] National Voluntary Laboratory Accreditation Program, National Institute of Standards and Technology, Bldg 101, Room A-807 Gaithersburg, MD. 20899.
- [6] Jankovic, J.T., J.L. Clere, W. Sanderson, and L. Placitelli. Estimating Quantities of Asbestos in Building Materials. National Asbestos Council Journal, (Fall, 1988).
- [7] Title 40, Code of Federal Regulations, Part 763. Appendix A to Subpart F. Interim Method of the Determination of Asbestos in Bulk Insulation Samples, (April 15, 1988).
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- [11] Phillips, W.R. and D.T. Griffen, Optical Mineralogy, W. H. Freeman and Co., (1981).
- [12] McCrone, Walter, The Asbestos Particle Atlas, Ann Arbor Science, Michigan, (1980).
- [13] "Selected Silicate Minerals and their Asbestiform Varieties," Bureau of Mines Information Circular IC 8751, (1977).

METHOD WRITTEN BY:

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APPENDIX D

FEDERAL AND STATE APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARS)

**DRAFT - ARAR'S FOR THE HYDRATED BIOTITE SOIL REMOVAL AND DISPOSAL
BURLINGTON NORTHERN SANTA FE RAILWAY COMPANY
LIBBY, MONTANA**

29 CFR 1910.134	Use of respiratory protection.	<ul style="list-style-type: none"> • Each employer will be responsible for compliance with this standard. • Full-face PAPR's will be used initially with the possibility of downgrading to negative pressure full-face respirators.
29 CFR 1910.134, 29 CFR 1926.95, 29 CFR 1926.96, 29 CFR 1926.100, 29 CFR 1926.101, 29 CFR 1926.102, 29 CFR 1926.103	Site work requires the use of personal protective equipment.	<ul style="list-style-type: none"> • Personal protective equipment is to be worn on-site at all times. The minimum personal protective equipment will include a hard hat, safety glasses, safety boots, and hearing protection during vacuum truck operation. This equipment will comply with applicable ANSI standards. • Additional personal protective equipment required in the Contamination Reduction Zone and Exclusion Zone and this will include respiratory protection, disposal suits, and protective gloves.
29 CFR 1910.151(b)	In the absence of an infirmary, clinic, or hospital in near proximity to the workplace which is used for the treatment of all injured employees, a person or persons shall be adequately trained to render first aid. Adequate first aid supplies shall be readily available.	St John's Lutheran Hospital at 350 Louisiana Avenue, Libby, is less than one mile from the work areas. Therefore, this regulation is not applicable.

**DRAFT - ARAR'S FOR THE HYDRATED BIOTITE SOIL REMOVAL AND DISPOSAL
BURLINGTON NORTHERN SANTA FE RAILWAY COMPANY
LIBBY, MONTANA**

29 CFR 1926.1101 (29 CFR 1910.1001)	Worker protection measures to include engineering controls, worker training, labeling, respiratory protection, bagging of waste, 0.1 f/cc eight-hour time-weighted average and 1 f/cc 30-minute excursion permissible exposure limit.	<ul style="list-style-type: none"> • Requirements of these standards have been addressed in the project specification. Some of the worker protection measures are listed below. • Engineering controls will include keeping the soil wet and decontamination facilities for personnel and equipment. Additionally, the HEPA-filtered vacuum truck is another engineering control in that it captures dust generated in the vacuuming process. • Workers are to be trained in accordance with federal asbestos abatement requirements and licensed by the State of Montana for asbestos abatement work before starting work at the site. A requirement of asbestos licensure is that they have proper training for their job designation. • Plastic-wrapped soil in dumpsters will be labeled before it is transported off the site in bulk. Additionally, bags of waste will have the appropriate asbestos warning label. • Signs and/or warning tape and traffic cones will be used at the site perimeter to keep unauthorized personnel out of the site and Exclusion Zone. • Waste generated from personal protective equipment and during decontamination is to be disposed of in asbestos warning-labeled 6-mil bags. The bags are to be leak-tight polyethylene bags labeled in accordance with 29 CFR 1910.1200(f) of OSHA's Hazard Communication standard. • Respiratory protection and protective clothing will be worn by personnel entering the Exclusion Zone. • Worker breathing zone samples will be collected from workers in the Exclusion Zone to document exposure. Additionally, area samples will be collected at the Exclusion Zone perimeter. Decisions to upgrade respiratory protection will be based on the airborne concentrations detected and the maximum use concentrations of the respirators being used.
40 CFR 61.154	Disposal of asbestos-containing waste	Material generated with the project is to be disposed of in a landfill operated by Lincoln County, Montana.

**DRAFT - ARAR'S FOR THE HYDRATED BIOTITE SOIL REMOVAL AND DISPOSAL
BURLINGTON NORTHERN SANTA FE RAILWAY COMPANY
LIBBY, MONTANA**

40 CFR Part 763.90	The removal project is completed after visible hydrated biotite has been removed and the soil samples do not detect Libby amphibole.	<ul style="list-style-type: none"> Each work area will be inspected and a "Certification of Visual Inspection" will be completed to document that each area has been visually inspected. EMR will collect soil samples to document Libby amphibole content of the soil following cleaning.
42 CFR Part 84	Respirator filter selection	Although other filters may provide adequate protection, P100 have been specified in the EMR Work Plan.
49 CFR parts 171 and 172	Regulates the transportation of asbestos-containing waste material. Requires waste containment and shipping papers.	A shipment record is to accompany the shipment to the landfill. A vessel lined with polyethylene sheeting will be used for waste transportation.
American National Standard for High-Visibility Safety Apparel ANSI/ISEA 107-1999	Exposure to vehicular equipment at the site.	Class 2 garments should be worn since they are intended for use in activities where greater visibility is necessary during inclement weather conditions or in work environments with risks that exceed those for Class 1.
ARAR's for preventing damage to unique or sensitive areas, such as floodplains, historic places, wetlands, and fragile ecosystems, and for restricting other activities that are potentially harmful because of where they take place.	Site work	The project site is a BNSF Railroad Company right-of-way. Therefore, issues with respect to floodplains, historic places, wetlands, fragile ecosystems, or activities that may be potentially harmful are not applicable.
Backup Alarm - citable under Section 5(a) (1) of the Occupational Safety and Health Act.	Under Section 5(a)(1) of the Occupational Safety and Health Act (the General Duty Clause), employers must keep their workplaces free from recognized hazards	Backup alarms on heavy equipment are required.

**DRAFT - ARAR'S FOR THE HYDRATED BIOTITE SOIL REMOVAL AND DISPOSAL
BURLINGTON NORTHERN SANTA FE RAILWAY COMPANY
LIBBY, MONTANA**

Emission Control requirements of 40 CFR 61.145 and Waste handling provisions of 40 CFR 61.150	Prevent visible emissions during vacuuming, soil transfer, loading the soil into vessels for transfer to the landfill.	<ul style="list-style-type: none">• The HEPA-filtered vacuum trucks will capture airborne particulate as it is generated in the vacuuming process and thus prevent visible emissions. Additionally, soils are to be wetted prior to handling and they are to remain wet throughout handling so that no visible emissions are released from the site.• Soils for disposal will be transferred to a container lined with 6-mil polyethylene sheeting and waste will be transported to the landfill in bulk.• Each truckload of soil will be manifested using a special waste manifest. Photocopies of the manifests will be retained by EMR and the originals will be supplied to BNSF for their records.• Air sampling will be conducted during vacuuming, loading, and decontamination procedures in order to sample for potential airborne fibers.
	Asbestos-containing waste transportation and disposal at the approved landfill.	<ul style="list-style-type: none">• EMR on behalf of BNSF and the transporter will ensure that a waste shipment record has been appropriately completed and signed by the generator, and accompanies the waste to the disposal site.• A copy of the waste shipment record is to be provided to the landfill operator or owner.• A copy signed by the landfill owner or operator is to be returned to BNSF within 30 days.

**DRAFT - ARAR'S FOR THE HYDRATED BIOTITE SOIL REMOVAL AND DISPOSAL
BURLINGTON NORTHERN SANTA FE RAILWAY COMPANY
LIBBY, MONTANA**

29 Code of Federal Regulations 1910.145(d)(4)	Caution signs warning of asbestos-containing material and/or asbestos-related activity.	<p>Vessels used to transport asbestos-containing waste material are to be posted during the loading and unloading of waste so that the signs are visible. The posting must:</p> <p>(1) Be displayed in such a manner and location that a person can easily read the legend.</p> <p>(2) Conform to the requirements for twenty inch by fourteen-inch [50.8-centimeter by 35.56-centimeter] upright format signs specified in title 29 Code of Federal Regulations 1910.145(d)(4) and this paragraph; and</p> <p>(3) Display the following legend in the lower panel with letter sizes and styles of a visibility at least equal to those specified below.</p> <table><tr><th>Legend</th><th>Notation</th></tr><tr><td>DANGER</td><td>2.5 cm [1 in.] Sans Serif, Gothic, or Block.</td></tr><tr><td>ASBESTOS DUST HAZARD</td><td>2.5 cm [1 in.] Sans Serif, Gothic, or Block.</td></tr><tr><td>CANCER AND LUNG DISEASE HAZARD</td><td>1.9 cm [3/4 in.] Sans Serif, Gothic, or Block.</td></tr><tr><td>Authorized Personnel Only</td><td>14 Point Gothic</td></tr></table>	Legend	Notation	DANGER	2.5 cm [1 in.] Sans Serif, Gothic, or Block.	ASBESTOS DUST HAZARD	2.5 cm [1 in.] Sans Serif, Gothic, or Block.	CANCER AND LUNG DISEASE HAZARD	1.9 cm [3/4 in.] Sans Serif, Gothic, or Block.	Authorized Personnel Only	14 Point Gothic
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Montana Title 75. Environmental Protection Chapter 2. Air Quality, Part 5. Asbestos Control	Montana Department of Environmental Quality (DEQ) asbestos-related regulations.	<p>Most of the Montana DEQ regulations are not applicable because the project does not involve asbestos-containing materials in an indoor environment and material containing one percent or greater asbestos has not been detected at the site. However, there will be compliance with the following that may be applicable and/or relevant:</p> <ul style="list-style-type: none">• Site workers will be required to be accredited by Montana DEQ.• A courtesy notification will be sent to Montana DEQ, but a permit is not required since material containing at least one percent asbestos has not been detected at the site.										

APPENDIX E

KEY PERSONNEL RESUMES

QUALIFICATIONS

I am certified industrial hygienist with over 17 years of health and safety consulting experience. My experience has included nearly all aspects of OSHA compliance including exposure monitoring and sampling, compliance audits, program development, and training.

Clients have included federal government (Army Corps of Engineers, FAA, US Postal Service, and Veteran's Administration), state and local governments, architects, contractors, engineers, health care providers, insurance companies, large and small industry, law firms, and transportation.

I served as a corporate health and safety director at Maxim Technologies, Inc., safety committee member at Braun Intertec, and the Office Safety Coordinator at HDR Engineering, Inc.

WORK HISTORY

2001-Present

Principal, Environmental Health, Inc.

I am the sole proprietor of Environmental Health, Inc. I have aided with logistical arrangements for a client's their mobile medical monitoring program, collected exposure samples and performed noise monitoring. Additionally, I have written material safety data sheets and provided consultation for construction activity at a site where hazardous materials were present.

1997-2001

Senior Industrial Hygienist, HDR Engineering, Inc. - Senior Industrial Hygienist, Braun Intertec Corporation

I was responsible for performing investigations and health and safety audits, training, and project management for OSHA-compliance and indoor air quality projects. The highlights of my work are as follows:

- Collected exposure samples for chemicals and noise. Data was interpreted and recommendations for abatement were provided in a written report to clients.
- Developed numerous OSHA-required plans and programs: these have included process safety management plans for highly hazardous chemicals and associated training.
- Developed site safety plans for hazardous waste site work and provided all levels of the associated hazardous waste site operations training and emergency response training.
- Performed compliance audits for all areas of OSHA compliance, including; asbestos, confined space entry, electrical safety, emergency response, fire safety, housekeeping, lead, lockout/tagout, noise exposure, personal protective equipment, powered industrial trucks, program development, record keeping, training, and working and walking surfaces.
- Performed microorganism investigations for insurance companies and office building owners. Duties have included air, bulk, and surface sample collection and writing reports to the client with data interpretation and recommendations for abatement.

- I served on the Safety Committee at Braun Intertec and serving as the Office Safety Coordinator (OSC) for HDR. OSC duties include conducting health and safety committee meetings, OSHA-compliance training and record keeping, accident and injury record keeping and reporting, office safety audits, and medical surveillance coordination. The office safety program went from a program the met requirements to an exemplary program while I was the OSC.

1991-1997 and
1985-1988

Senior Industrial Hygienist-Health and Safety Director, Twin City Testing-Huntingdon Engineering-Maxim Technologies

I was responsible for project management of OSHA-related and indoor air quality work. My work included the following:

- Designed and oversaw asbestos and lead abatement projects.
- Conducted exposure studies and audits related to OSHA compliance for external clients and internally. I performed workplace exposure and microorganism sampling and provided reports with data interpretation and recommendations for abatement.
- Provided the following training to external clients and internal clients: confined space entry, forklift operator, hazard communication, hazardous waste site operations, personal protective equipment, and respiratory protection.
- Conducted health and safety audits of 500 to 600 FAA facilities.
- Provided expert testimony for Workers' Compensation cases.
- I was the Health and Safety Director for Maxim Technologies' northern region that included approximately 500 employees. Duties included OSHA-compliance training, record keeping, accident and injury record keeping, office safety audits, Workers' Compensation program, implementation of the drug and alcohol testing program, and medical surveillance coordination.

I was also involved with the following:

- Taught courses at Hennepin Technical College (Eden Prairie), Minnesota Safety Council, and the Midwest Center for Occupational Safety and Health.
- Served on the advisory committee for the Hennepin Technical College Environmental Chemistry program.

1988-1991

Office Manager-Department Manager, Delta Environmental Consultants, Inc. Managed 8 to 12 staff, project manager, and responsible for field work and training. I performed asbestos and lead inspections. As a project manager, developed abatement specifications, held pre-bid and progresses meetings, acted as the owner's representative and oversaw abatement projects. I performed OSHA-compliance monitoring and indoor air quality investigations.

1976-1980

Hospital Corpsman, US Navy

I served as an emergency medical technician and ocular technician. I was awarded letter of commendation from the Commanding Officer of the Naval Regional Medical Center-Oakland for correctly diagnosing and timely referral of a patient with an acute eye condition. Was "Sailor of the Month" for the Naval Regional Medical Center Regional Clinic-Moffett Field. I was honorably discharged.

EDUCATION

- 1984 BA, Augsburg College
Physics major with a math minor
- 1990 MS, University of Minnesota
Environmental Health with an industrial hygiene emphasis

LICENSES & CERTIFICATES

- American Board of Industrial Hygiene, Certified Industrial Hygienist (1991).
- Certificates for a variety of short courses including fungi sampling and evaluation, professional writing, ergonomics, and process safety management.
- Formerly certified as an asbestos inspector, management planner, designer, and lead inspector.

INTERESTS & ACTIVITIES

- Coached hockey for the Rosemount and Eagan hockey associations for a total of nine years. Currently a Director with the Eagan Hockey Association.
- Coached baseball and soccer for three seasons in Eagan.

Experience Profile
Don Clabaugh, PE
Principal Engineer

EDUCATION

M.S. Engineering Geology, University of Akron, 1984
B.S. Engineering Geology, University of Kansas, 1983

PROFESSIONAL AFFILIATIONS

Professional Engineer (Civil/Sanitary) in Washington, Oregon, Idaho, Kansas, Illinois and Alaska
National Groundwater Association

EXPERIENCE SUMMARY

Mr. Clabaugh has 18 years of experience as an environmental consultant. He is currently Vice President in charge of Western Operations, and manages projects and personnel in EMR's Denver, Fort Worth and Seattle offices. Mr. Clabaugh has specific technical expertise in civil engineering, regulatory compliance and litigation support, and is a recognized expert in the field of hydrogeology. He was the invited moderator for the Ground water Geochemistry Conference sessions on ground water monitoring well materials compatibility hosted by the National Ground water Associations. Mr. Clabaugh also was a reviewer for the "Green Book" (the US EPA guidance manual on ground water monitoring).

Mr. Clabaugh was the Project Manager for the RI/FS on the largest operable unit of the largest NPL site in the country; the Old Works East Anaconda Development Area of the Clark Fork NPL Site in Anaconda, Montana. At that site and other mining-related sites, Mr. Clabaugh used his technical expertise in unsaturated zone hydrology, mineral- and hydrogeo-chemistry, groundwater and colloid transport of metals, and hydraulic design to complete the RI/FS and remedial design.

Mr. Clabaugh has specific technical expertise in the following areas:

- Conducting remedial investigations and feasibility studies (RI/FS), risk-based corrective actions and Brownfields projects with emphasis on risk- or remedial-action focused cost effective solutions.
- Remedial design of well and trench systems, soil vacuum extraction (SVE), air sparging, steam injection vapor extraction (SIVE), slurry walls, solidification systems, and soil and water treatment.
- Compliance and monitoring programs for federal and state regulations including CERCLA, TSCA, RCRA, CWA, UST, MTCA, GWQS and SPCC.
- Water supply development and well design. Siting new ground-water supplies in buried valley systems using surface geophysics followed by boring programs and aquifer tests. Design and construction of vertical or horizontal (radial collector) wells to minimize operation and maintenance costs.
- Permitting, design and operation of RCRA Subtitle D and municipal landfills. Use of statistical/chemical equilibria evaluations to minimize ground-water monitoring requirements.

SELECTED PROJECTS

Whiting Refinery/J&L Landfill Remedial Design, Whiting, Indiana.

Remedial Engineer \ Project Manager. Designed interceptor trench systems, recovery wells, dual phase extraction wells, and well point systems for recovery of free phase and dissolved hydrocarbons and hydraulic control of the site boundary at a 700-acre CERCLA NPL refinery/landfill. Efforts included Engineering Evaluation/Cost Analysis (EE/CA) and FS preparation, geochemical modeling, preparation of master remediation plans, pumping test analysis, hydraulic design, and performance modeling.

Motorola Mountain-Top Generator ASTs, Schaumburg, Illinois.

Completed investigation and cleanup of aboveground storage tank (AST) spills, including soil and groundwater contamination, at sites ranging from Florida to Alaska.

Virginia Wood Preservers (Rentokil) RI and EE/CA, Richmond, Virginia.

Conducted an RI at an operating NPL status wood treating plant. Contaminants were creosote, pentachlorophenol and copper chromate arsenate. Geophysics, soil and groundwater sampling, pumping tests and groundwater modeling were utilized to evaluate fate and transport. Evaluated remediation including bioaccumulation, excavation, and interceptor trench systems. Remedial costs were compared in an EE/CA.

UST Site Remedial Design, various sites in Washington, Oregon, Kansas, Missouri, and Nebraska.

Project Manager/ Senior Engineer for Amoco, Texaco, Time, Sinclair and others. Designed and supervised installation of recovery wells, interceptor trenches, soil vacuum extraction and air sparging systems for over 36 sites. Managed up to 14 staff performing site investigations of petroleum contamination by soil gas survey, geoprobe, boring and well installation and sampling at over 130 sites.

RCA/Thomson Circleville Facility RI, Circleville, Ohio.

Senior Hydrogeologist. Investigated lead contamination of groundwater at a CERCLA site, including hydrostratigraphic analysis, groundwater treatment contingency planning, and transport and fate of dissolved and colloidal lead in groundwater.

Riverfront Wellfield Contamination, Sioux City, Iowa

Project Manager. Delineated the extent of PCBs and diesel fuel, and developed a workplan to further characterize the site and develop remedial measures. Geophysical and soil gas surveys and a groundwater monitoring program were utilized to monitor contamination entering the wellfield and to provide water supply protection.

Millard Avenue Expansion, Toledo, Ohio

Senior Engineering Geologist. Completed a CERCLA-format workplan, QAPP and RAO for expansion of a road through an industrial area with soil and groundwater contamination from numerous landfills, CERCLA sites and the largest active hazardous waste landfill in the country. DOT regulations required compliance with CERCLA regulations and guidelines with agency review and negotiations. Used a soil gas survey and hydrostratigraphic analysis to preliminarily characterize the site.

Dura Road Landfill, Toledo, Ohio

Senior Engineering Geologist. Hydrogeological investigation for an RI/FS at a pre-RCRA landfill site. An extensive geophysical exploration was conducted to delineate the extent of waste. PCB's, oily-wastes, organic solvents and metals were detected in groundwater and multiple soil zones using a special drilling and casing program to minimize cross-contamination of soil zones.

CECOS Aber Road Facility, Clermont County, Ohio

Project Manager \ Senior Engineer. Conducted a comprehensive hydrostratigraphic analysis and waste cell design evaluation at a large TSCA/RCRA hazardous waste disposal facility. Review included investigation of groundwater contamination, monitoring and statistical evaluation procedures and results, HDPE-liner installation in freezing temperatures, cell closure methods, and drum handling and waste treatment facility decommissioning procedures. Provided litigation support and expert witness service.

Central Ohio Landfill, Mount Vernon, Ohio

Project Manager. Modified closure plan was completed for an existing landfill nearing capacity. Design included monitoring systems, abatement of leachate springs with horizontal gravity-fed screens, routing and treatment of leachate, and a cover liner.

Model Landfill, Columbus, Ohio

Senior Engineering Geologist. Conducted a geotechnical and hydrogeological investigation for a modified closure plan. Developed a groundwater flow and solute transport (numerical) model to evaluate various remedial designs for management of the leachate and cover lining.

Triangle Landfill, Chillicothe, Ohio

Senior Engineering Geologist. Conducted a subsurface and geotechnical investigation for expansion of an existing landfill. Surface geophysics and test borings were used to determine the amount of suitable cover material and the proper configuration for the expansion cell.

Knox County Proposed Landfill, Mount Vernon, Ohio

Project Manager. Completed a geotechnical and hydrogeological evaluation for the permit-to-install application for a municipal landfill site. Designed a groundwater monitoring system and multiple waste cells. Utilized surface geophysics and borings.

Marion County Landfill, Marion, Ohio

Project Manager. Completed geotechnical and hydrogeological studies for the siting and design of a municipal landfill. Surface geophysics, pumping tests and a groundwater model were utilized. Installed the groundwater monitoring system, and designed the waste cells with a slurry cut-off wall, synthetic liner and leachate collection system.

Henrico County Landfill, Richmond, Virginia

Project Hydrogeologist. Completed geophysical and hydrogeological studies to estimate the fate and transport of leachate from an existing landfill.

Hillyard Dross RI/FS, CAP, Spokane, Washington.

Project Manager and Senior Engineer for a BNSF leasee site with over 100,000 cubic yards of aluminum dross and associated contaminated soil. The aluminum dross piles contain concentrations of fluoride, nitrates, chloride and ammonia that are of potential concern for

human health and ecological receptors. Completed an RI/FS and engineering. PRP negotiations are ongoing, and construction is expected for Fall 2001. Fate and transport evaluations, and a baseline risk assessment, were completed to determine whether the presence and concentration of contaminants posed a significant risk to human health or the environment. Alternatives that were considered in the FS were: no action; institutional controls with long-term ground-water monitoring; excavation with off-site disposal; and, on-site containment beneath a multi-media cap. The Engineering Design Report detailed the specifications for the remedial solution, which was to install a limited-use landfill for the aluminum dross and contaminated soil.

Portland ANGB RI/FS, Portland, Oregon.

Managed over \$2.5M in work orders completing Remedial Investigation/Feasibility Study (RI/FS), Engineering Evaluation/Cost Analysis (EE/CA) and Interim Removal Action (IRA) under the Department of Defense (DOD) Air National Guard (ANG) Installation Restoration Program (IRP) for a site with soil and groundwater contaminated by VOCs, SVOCs and metals. Chlorinated solvents in groundwater are present at elevated levels upgradient of the City of Portland wellfield. Investigation included hydropunch, boring and monitoring well installation and sampling, treatability studies (in-well aeration) and aquifer testing. Data evaluation included ground-water and solute transport modeling, assessment of natural attenuation and risk assessments. EE/CA evaluation included excavation, SVE, bioremediation and treatment methods for soil contaminated with chlorinated solvents. FS included in-well aeration, natural attenuation, and containment strategies.

Southern Pacific Sacramento Rail Yard Interim Remedial Action, Sacramento, California.

Project Manager for a CERCLA RI/FS on the Lagoon Groundwater operable unit, and Senior Engineer on the South Plume Interim Remedial Action program. The site is currently the largest Brownfields Redevelopment site on the west coast. Tasks included sampling and aquifer testing plans, soil and groundwater data collection and evaluation, design of an 8 well extraction system, permitting (NPDES) for surface water discharge, preparation of RI Workplans, and preparation of an RI.

Smelter Hill NPL Site OW/EADA operable unit RI/FS, Anaconda, Montana. Project Manager for an operable unit of the Clark Fork NPL Site. Completed an RI/FS for the 1,340-acre Old Works/East Anaconda Development Area CERCLA NPL smelter site. Completed data collection and evaluation activities for a historic copper mine with soil and groundwater contamination by metals. Site considerations included disposition of over 1.4 million cubic yards of waste materials, stabilization of waste-impacted soils, evaluation of vadose zone transport at a semi-arid site, and complex stream-aquifer (transport and fate) relations. Responsible for negotiations with EPA and MDHES, and a related project completing remedial action objectives and feasibility of groundwater treatment systems.

McChord Air Force Base SIVE System, Washington

Remedial Engineer responsible for senior review of system design and modeling for implementation and pilot testing of a Steam Injection Vapor Extraction (SIVE) system for extraction of volatile organic contaminants from the unsaturated zone.

Experience Profile
David L. Welch
Project Geologist

EDUCATION

B.S. Geology, Western Washington University, Bellingham, WA, 1984

REGISTRATIONS/ CERTIFICATIONS

International Fire Code Institute-Certified Washington UST Site Assessor
AHERA Asbestos Building Inspector
AHERA Asbestos Management Planner
AHERA Asbestos Abatement Contractor/Supervisor
AHERA Asbestos Project Designer
California-OSHA Certified Asbestos Consultant
NIOSH 582 Course: Sampling and Evaluating Airborne Asbestos Dust
EPA-Accredited Lead Inspector/Risk Assessor Training Course
NITON XRF 7000 Series Training Course
EPA Lead Risk Assessor (WA, AK, ID, NE)
Oregon Lead Risk Assessor

FIELDS OF SPECIALIZATION

- ◆ Asbestos Project Design
- ◆ Asbestos Operation and Maintenance (O&M) Plans
- ◆ Asbestos Operation and Maintenance (O&M) 16 hour Training Course Instructor
- ◆ Asbestos Building Inspections and Abatement Oversight
- ◆ Asbestos Air Monitoring and PCM Analysis by NIOSH 7400
- ◆ Computer Aided Drafting (CAD)
- ◆ Lead-based paint Inspections/Risk Assessments
- ◆ Hydrocarbon Assessment/Remediation
- ◆ State RCRA Program: Model Toxics Control Act (MTCA) Cleanup Regulation Program, State of Washington: Remedial Investigation/Feasibility Studies (RI/FS)
- ◆ Independent Remedial Action Process (IRAP)
- ◆ Dangerous Waste Manifests
- ◆ Phase I Environmental Site Assessments under ASTM "Due Diligence"
- ◆ Phase II Environmental Site Assessments

REPRESENTATIVE PROJECT EXPERIENCE

Mr. Welch has fourteen years experience in the environmental field. Mr. Welch has served as Project Manager/Project Geologist on assignments related to asbestos building inspections and abatement oversight, asbestos project design specifications, asbestos air monitoring, asbestos Operation and Maintenance (O&M) plans and training, assessment and remediation of contaminated soil and groundwater, Phase I Environmental Site Assessments and CADD design. His asbestos experience includes managing projects in Washington, Oregon, Idaho, Montana, Arizona and California. His geotechnical experience has been focused on state-equivalent RCRA, and UST programs in Washington, Oregon, California and Nevada. Mr. Welch has primary experience in hydrocarbon contamination but has also managed projects relating to mineral spirits, PCE, and lead. Mr. Welch has been involved with a variety of traditional and innovative remediation technologies, including pump and treat systems, vapor extraction, bio-enhanced vapor extraction, air sparging and aboveground bioremediation cells. Mr. Welch has experience in supervising drilling

assessment projects utilizing hollow stem auger, mud rotary and air rotary technology, and installation of groundwater monitoring wells, recovery wells, and vapor extraction wells.

Relevant Projects including Job Title and Job Responsibilities

- **Independent Remedial Action, Spokane, Washington** - Managed an Independent Remedial Action under MTCA on a former foundry site with extensive lead contaminated soils. Conducted subsurface characterization and remedial investigation on site. Collected data from quarterly groundwater monitoring program on site that indicated lead was not leaching into a shallow groundwater table within the zone of highest soil contamination. Cleanup alternatives were evaluated with a multi-layer impermeable cap and imposed institutional controls proposed for a long-term solution.
- **Subsurface Characterization/Remedial Action, Bellevue, Washington** - Assisted in field assessment, modeling and reports pertaining to a release of tetrachloroethane (PCE) into subsurface soils at a former dry-cleaning facility. The project was concurrent with a contracted development of the property into an upscale shopping center. The project underwent an IRAP coordinated with the Washington State Department of Ecology (WDOE).
- **System-Wide Asbestos Program, Major Railroad** - Conducted asbestos inspections, re-inspections, pre-design survey, CADD design, design specification manuals, project site management/air monitoring and building inspection reports for project sites in 22 states.
- **System-Wide Vermiculite Characterization and Removal Program, Major Railroad**—provided expertise in developing building inspections, pre-design surveys, CADD design, design specifications manuals, and project site management/air monitoring for managing vermiculite in 22 states.
- **Asbestos Management-Major Bank** - Project management, survey, design and project site management during removal of asbestos-containing materials at four bank branches undergoing remodel in the Puget Sound area. Work was conducted at night during off hours and had special security access protocols that were adhered to.
- **Asbestos Management - Truck Manufacturer** - Project management, facility survey, design specifications, Operation and Maintenance Plan, awareness training seminars at Seattle plant. Survey required lift access coordination and site safety considerations.
- **Asbestos Management - Multi-tenant Commercial Building Owner** - Project management, facility survey, design specifications manual, proposed Operation and Maintenance Plan and awareness training seminars. Survey was conducted for existing owner as part of an interested buyer's request. Project conducted concurrently with independent remedial action for this former bulk fuel terminal. Proposed multiple options and costs for asbestos management/removal depending on future site use.
- **Asbestos Management - Major Railroad** -designed and implemented a 16 hour Operation and Maintenance (O&M) training program tailored for structures and telecom personnel
- **Phase I ESA, Asbestos Building Inspection, Project Design Specifications and Project Site Management/Air Monitoring - Industrial Building Owner Partnership** - Conducted Phase I ESA/AHERA building inspection for design and removal of all friable asbestos-containing materials. The project was conducted within the proposed budget and schedule.

Experience Profile

Scott J. Rhen

Asbestos/Lead Inspector/Air Monitoring Professional
Project Specialist

EDUCATION/REGISTRATIONS

B.S. Geology, (1984) University of Nebraska - Lincoln
AHERA Accredited Contractor/Supervisor
AHERA Accredited Inspector/Management Planner
Nebraska Law, Rules, and Regulations Governing Asbestos Projects Course
Sampling and Evaluation Airborne Asbestos Dust-NIOSH 582 Equivalent Course

CERTIFICATIONS/MEMBERSHIPS

Air Monitoring Professional - Missouri
EPA-accredited AHERA Contractor/Supervisor — multiple states
EPA-accredited AHERA Inspector — multiple states
EPA-accredited AHERA Design — multiple states
AIHA Asbestos Analysis Registry
Radiation Safety Training - XRF
OSHA 40-hour Hazardous Waste Site Operations Worker/Supervisor
Phase I Environmental Site Assessment Training
Geological Society of America

FIELDS OF SPECIALIZATION

- ▼ Asbestos Inspections
- ▼ Air Monitoring/Industrial Hygiene
- ▼ Asbestos Project Design
- ▼ Lead-based Paint Testing Sampling and Detection
- ▼ Radiation Safety
- ▼ Radon Sampling

RELEVANT EXPERIENCE

Mr. Rhen has 14 years of environmental expertise in a broad range of project activities. He has performed field duties and managed asbestos inspections, project design and industrial hygiene air monitoring for projects ranging from major multi-state, nationwide system-wide industrial plant facilities to individual single-family residences. He has supervised projects involving monitoring for airborne particulates, asbestos removal projects and analytical laboratory processes. He has met qualification and licensing requirements and performed field work activities in at least 19 states.

Mr. Rhen is a Quality Assurance team leader responsible for reviewing air sample analytical tests performed by 14 project field technicians. In this role, Scott provides routine re-training and instruction for laboratory technicians to continually monitor and improve performance quality and education.

He has monitored air for lead and coal dust during construction and demolition activities. He performed as the air monitoring professional on an \$800,000 remediation at a State of Montana Superfund asbestos cleanup. He has tested school systems in Iowa for Radon and performed school AHERA initial and re-inspections.

Mr. Rhen also participated in a lead-based paint survey utilizing advanced Niton XRF technology and bulk paint chip sample collection and analysis to survey 12,000 rail car units in 1998.

Mr. Rhen has experience in soil and groundwater contamination investigations, supervision of groundwater monitoring well installations and remediation system operation. He has conducted groundwater measurements at an EPA CERCLA Superfund site and has extensive experience working on railroad yards.